This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

NYPL RESEARCH LIBRARIES
3 3433 06636753 7

THE NEW YORK PUBLIC LIBRARY
ASTOR LENOX & TILDEN
FOUNDATIONS

METROPOLITAN SEWERAGE COMMISSION
OF NEW YORK,
17 BATTERY PLACE.
BOARD OF ESTIMATE AND APPORTIONMENT 34

PRINCIPLES OF SEWAGE TREATMENT.

CHARLES GRIFFIN & CO., LTD., PUBLISHERS.

THIRTEENTH EDITION, Thoroughly Revised. Fully Illustrated. Price $2.00.

PRACTICAL SANITATION:

A Handbook for Sanitary Inspectors and Others interested in Sanitation.

BY GEORGE REID, M.D., D.P.H.,
Fellow, Mem. Council, and Examiner, Sanitary Institute of Great Britain, and Medical Officer to the Staffordshire County Council.

With an Appendix on Sanitary Law (Rewritten).

BY HERBERT MANLEY, M.A., M.B., D.P.H., BARRISTER-AT-LAW.

"A VERY USEFUL HANDBOOK, with a very useful Appendix. We recommend it not only to SANITARY INSPECTORS, but to HOUSEHOLDERS, and ALL interested in Sanitary matters."—*Sanitary Record.*

SECOND EDITION, Revised. In Crown 8vo. Handsome Cloth. Profusely Illustrated. $2.50 net.

SANITARY ENGINEERING:

A Practical Manual of Town Drainage and Sewage and Refuse Disposal.

For Sanitary Authorities, Engineers, Inspectors, Architects, Contractors, and Students.

BY FRANCIS WOOD, A.M.Inst.C.E., F.G.S.,
Borough Engineer and Surveyor, Fulham; late Borough Engineer, Bacup, Lancs.

"A VERITABLE POCKET COMPENDIUM of Sanitary Engineering. . . . A work which may, in many respects, be considered as COMPLETE . . . COMMENDABLY CAUTIOUS . . . INTERESTING . . . SUGGESTIVE."—*Public Health Engineer.*

Beautifully Illustrated, with numerous Plates, Diagrams, and Figures in the Text. $6.50 net.

TRADES' WASTE:

ITS TREATMENT AND UTILISATION.

A Handbook for Borough Engineers, Surveyors, Architects, and Analysts.

BY W. NAYLOR, F.C.S., A.M.Inst. C.E.

"There is probably no person in England to-day better fitted to deal rationally with such a subject."—*British Sanitarian.*

With Four Folding Plates and numerous Illustrations. Large 8vo. $3.00 net.

WATER SUPPLY:

A Practical Treatise on the Selection of Sources and the Distribution of Water.

BY REGINALD E. MIDDLETON, M.Inst.C.E., M.Inst.Mech.E., F.S.I.

"As a companion for the student, and a constant reference for the technical man, we anticipate it will take an important position on the bookshelf."—*Practical Engineer.*

In Handsome Cloth. With 59 Illustrations. $2.00 net.

SMOKE ABATEMENT:

A Manual for the Use of Manufacturers, Inspectors, Medical Officers of Health, Engineers, and Others.

BY WILLIAM NICHOLSON,
Chief Smoke Inspector to the Sheffield Corporation.

"We welcome such an adequate statement on an important subject."—*British Medical Journal.*

LONDON: CHARLES GRIFFIN & CO., LTD., EXETER STREET, STRAND.
To be had of J. B. LIPPINCOTT COMPANY, PHILADELPHIA.

PRINCIPLES OF SEWAGE TREATMENT.

BY

PROFESSOR DR. DUNBAR,

DIRECTOR OF THE HAMBURG STATE HYGIENIC INSTITUTE.

TRANSLATED, WITH THE AUTHOR'S SANCTION, BY

H. T. CALVERT, M.Sc., PH.D., F.I.C.,

CHIEF CHEMICAL ASSISTANT, WEST RIDING OF YORKSHIRE RIVERS BOARD.

With 147 Illustrations.

LONDON:
CHARLES GRIFFIN & COMPANY, LIMITED.
PHILADELPHIA: J. B. LIPPINCOTT COMPANY.
1908.

[*All Rights Reserved.*]

BOARD OF ESTIMATE AND APPORTIONMENT
Office of the Chief Engineer
34

AUTHOR'S PREFACE.

DURING the last few years I have been repeatedly asked to write a comprehensive book on the sewage problem. About a year ago, when preparing a lecture on the then position of the subjects of river pollution and sewage treatment, I decided to abandon the scruples which I had previously held against writing such a book. I then thought the task was an easy one, for during the previous ten years or more I had carefully followed all matters connected with the sewage problem. However, I have had to make many inquiries and investigations, and my material has gradually become almost unlimited, so that it would now be easier for me to compile a work of reference than to write a short book on the principles of the subject. I do not consider the time ripe for the publication of a work of reference, because the whole problem of sewage disposal is developing just now at such a rapid rate that opinions which have been held for a very long time are daily giving way in the face of newly-established facts. Under these circumstances, those who have not been able to follow the separate phases of this development become hopelessly lost in attempting to follow the literature on the subject; they do not recognise all the new forms of apparatus which are mentioned and the new names which are used, and thus feel the need of a book dealing with the principles of the subject, a book written during the development itself, and grouping and critically describing the various phases of this development. Such a book cannot pretend to deal fully with all the numerous legal enactments and proposals which have been made with regard to sewage treatment.

Bearing all this in mind, I have repeatedly been forced to omit some facts which are of themselves valuable as supporting various opinions, and others which appeared to require further investigation before being finally accepted. Whilst the book has been passing through the press a considerable number of contributions to the subject have been published. I have tried to include these as far as possible in my material, but a full discussion will appear as a kind of appendix to this book in the pages of the *Gesundheits-Ingenieur*.

My wishes with regard to the form of the book and corrections and alterations during the printing have been most cordially met by the publishers, to whom I must here express my warmest thanks.

The number of authorities and colleagues to whom I am indebted for reports and publications is too large for specific mention here, and I have been obliged to omit full reference to some of the authors whose publications are discussed in the text. I have consulted over a thousand such publications, and hence it will be seen that the bibliography which I have included is incomplete.

The writing of the book has caused me many anxious moments, and I have often felt discouraged. I hope, however, that it is now sufficiently mature to face the world, and to fulfil its mission.

DR. DUNBAR.

HAMBURG,
July 26, 1907.

NOTE OF THE TRANSLATOR.

In attempting to introduce Prof. Dunbar's book to a wider circle of readers than that for which the German edition is available, I have adhered as closely as possible to the wording, and have in all cases expressed the sense of the original.

The excellent and thorough manner in which Prof. Dunbar has dealt with the subject, and the absence of an exactly similar work in English, have formed additional inducements for undertaking the translation. The book may be read with profit by all interested in the sewage problem.

I am indebted to Dr. H. Maclean Wilson, the Chief Inspector of the West Riding of Yorkshire Rivers Board, for his valuable criticism in reading through the manuscript, and to Prof. Dunbar for kindly reading the proof sheets and making some alterations and additions specially for this translation.

H. T. CALVERT.

WAKEFIELD,
September 1908.

CONTENTS.

PART I.—HISTORICAL DEVELOPMENT OF THE SEWAGE PROBLEM.

CHAPTER — PAGES
I. GROWTH OF RIVER POLLUTION 1-5
II. LEGAL MEASURES TAKEN BY CENTRAL AND LOCAL AUTHORITIES . 6-20
III. RISE AND DEVELOPMENT OF METHODS OF SEWAGE TREATMENT . 21-26
IV. EARLIER VIEWS ON METHODS OF SEWAGE TREATMENT. THEIR OBJECT AND UTILITY 27-29

PART II.—THE PRESENT POSITION OF SEWAGE TREAMENT.

V. CHARACTERISTICS OF SEWAGE 30-40
VI. OBJECTS OF PURIFICATION WORKS 41-42
VII. DESCRIPTION OF METHODS FOR THE REMOVAL OF SUSPENDED MATTERS—
  A. Detritus Tanks 43-47
  B. Sieves, Gratings and Screens 47-59
  C. Grease Extraction 59-65
  D. Settlement 65-80
  E. Septic Treatment 80-97
  F. Precipitation 97-100
VIII. METHODS FOR THE REMOVAL OF PUTRESCIBILITY—
  A. Surface Irrigation 101-118
  B. Land Filtration (Frankland's Intermittent Filtration) . 118-153
  C. Artificial Biological Methods 153-222
  D. Degener's Lignite Method 223-227
IX. THE DISINFECTION OF SEWAGE 228-244
X. SUPERVISION AND INSPECTION OF SEWAGE DISPOSAL WORKS . 245-255
XI. THE UTILITY AND COST OF VARIOUS METHODS OF SEWAGE TREATMENT 256-266
INDEX 267-271

SYNOPSIS OF CHAPTERS.

PART I.—HISTORICAL DEVELOPMENT OF THE SEWAGE PROBLEM.

Chapter I.—Growth of River Pollution. (Pp 1-5.)

Accumulation of filth, above or below ground, in the neighbourhood of dwellings—Introduction of water-closets—Contents conducted into cesspools and street drains—Water-carriage system of sewerage with outlets into streams—Systematic pollution of English rivers, of the Seine below Paris, of the Emscher.

Chapter II.—Legal Measures taken by Central and Local Authorities. (Pp. 6-20.)

Attempts to remove filth from the precincts of the towns—Authorities permit pollution of streams—Prohibition of river pollution (1858)—Appointment of Royal Commission on Pollution of English Rivers (1865)—Public Health Act (1872) Amendments Act 1875—Rivers Pollution Prevention Act 1876—Land treatment advocated—Formation of Joint Committees, Rivers Boards—Appointment of Royal Commission on Sewage Disposal, 1898—Interim Report—Urgent necessity for a Central Authority to deal with questions of river pollution—Second Report of the Royal Commission—Third Report of the Royal Commission, 1903—Relations of manufacturers to local authorities—Fourth Report of the Royal Commission, 1904—Tidal waters— Legal enactments in Germany— Penal Code, Civil Code, Trade Regulations, Epidemic Diseases Act—Imperial Council of Health (Reichsgesundheitsrat)—Case law (decisions of the German High Courts)—Provincial Acts—Prussian Water Bill—Prussian Order of 1901—Reports of the Imperial Council of Health—Regulation of the Emscher.

Chapter III.—Rise and Development of Methods of Sewage Treatment. (Pp. 21-26.)

Earliest irrigation farms in Great Britain—Sewage farms and health—Liebig's advocacy of irrigation—Agricultural chemical experiments at Rugby—General advocacy of irrigation on account of possible financial return—Propaganda for chemical precipitation and utilisation of sludge as manure—Frankland's criticism—Filtration experiments at Lawrence, Mass.—Repetition at London—Earliest irrigation farm at Bunzlau—Development of sewage treatment in Germany—Requirements of Scientific Deputation for Prussian Medical Matters too stringent—Von Pettenkofer's opposition—Development of treatment by settlement.

Chapter IV.—Earlier Views on Methods of Sewage Treatment—Their Object and Utility. (Pp. 27-29.)

Attempts at disinfection and deodorisation—Experiments on the utilisation of the manurial constituents—Standards of purity recommended by Frankland's Commission—English Local Government Board's insistence on land treatment—Acute aspect of the matter in Germany—Pathogenic organisms in the rivers.

PART II.—THE PRESENT POSITION OF SEWAGE TREATMENT.

Chapter V.—The Characteristics of Sewage. (Pp. 30–40.)

Appearance of sewage—Putrescibility and self-purification—Separate and combined sewerage systems—Storm overflows—Gulley traps—Sewer flushing—Trade wastes—Estimation of volume of sewage—Relation to water supply—Influence of chemical composition of water supply—Influence of soap used—Influence of fæcal matter—Calculation of amount of waste products—Suspended matter—Organic sulphur—Chlorides—Oxygen absorption—Loss on ignition—Ammonia—Organic nitrogen—Albuminoid ammonia—Organic carbon—Bacteria—Signs of river pollution.

Chapter VI.—Objects of Purification Works. (Pp. 41–42.)

Dilution in the stream—Infection of rivers—Removal of the grosser suspended solids — Separation of all suspended matters — Removal of putrescibility — Sterilisation.

Chapter VII.—Description of Methods for the Removal of Suspended Matters. (Pp. 43–100.)

A. Detritus tanks—Inclination of tank bottom—Bucket elevators and grabs. (Pp. 43–47.)

B. Sieves, gratings, and screens—Fixed gratings—Filtration—Matting, rough surfaces, horizontal and inclined gratings, basket work, Metzger's automatic apparatus, rotating rakes—Paris, Manchester—Riensch, Schneppendahl, Uhlfelder—Allenstein —John Smith & Co.—Herzberg—Glasgow, Hamburg—Latham, Friedrich, Riensch's circular sieve, Joerning and Sauter, centrifugal machines. (Pp. 47–59.)

C. Grease extraction—Quantity of grease in sewage—Degener's experiments—Cassel —Wool washing in Yorkshire—Frankfurt—Kremer's method—Grease in Berlin sewage. (Pp. 59–65.)

Settlement, septic tanks and precipitation. (Pp. 65–100.) Definition. (P. 65.)

D. Settlement—Intermittent and continuous settlement—Shape of tanks, inclination of tank bottom, scum boards—Experiments at Hanover by Bock and Schwarz —Steuernagel's experiments at Cologne, the Cologne tanks—Loss of head, deep tanks —Müller-Nahnsen's method at Halle—Kniebühler's method at Dortmund—Mairich's method at Stargard and Neustadt—Ohrdruf and Birmingham—Dervaux, Dibdin's slates — Travis' parallel plates — Removal of sludge: Fidler's method, Ashton's method, dredgers, depressions or funnels in the tank bottom—Precipitation towers. (Pp. 65–80.)

E. Septic treatment—Cameron—Earlier ideas on putrefaction—*Fosses Mouras*—Alexander Müller — Hamburg experiments — Scum on tanks — Nuisance from smell — Calculation of settlement effected — Duration of putrefactive processes — Equalisation of the sewage—Decrease in putrescible dissolved solids—Sulphuretted hydrogen fixed, less for biological filters to deal with—Best kind of preliminary treatment before biological filters—Sludge digestion—Suspended matter in effluents from septic tanks—Consistence of the sludge—Hamburg experiments on sludge digestion—Bacterial and enzyme action—Size of septic tanks—Lowered cost for sludge removal—Small installations require little management—Covered septic tanks—Influence on pathogenic organisms—Scott Moncrieff's cultivation tank—Criticism of septic methods. (Pp. 80–97.)

F. Precipitation—Historical development—Hopes of financial return—Disappointment—Sludge presses—Precipitation at London, Glasgow, and Leipsic—Precipitation prior to biological treatment—Bolton, Salford, Leeds. (Pp. 97–100.)

METROPOLITAN SEWERAGE COMMISSI
OF NEW YORK,
17 BATTERY PLACE.

CHAPTER VIII.—METHODS FOR THE REMOVAL OF PUTRESCIBILITY. (Pp. 101-227.)

A. Surface irrigation — Historical sketch — Hopes of utilisation of manurial value—Clay soils—Attempts to make these fit for use—Peaty soils—Distribution of the sewage—Various methods—Drainage—Cost of preparing land—Planting sewage farms to utilise manurial value—Opposition of economics and sanitation—Results obtained and safety of working—Quantitative results—Influence of evaporation, sub-soil and rain water—Influence of trade effluents—Inorganic salts and grease in sewage—Preliminary treatment—Life of sewage farms—Sanitary results. Removal of bacteria and pathogenic germs—Chemical nature of the effluents. (Pp. 101-118).

B. Land filtration (Frankland's intermittent filtration) — First experiments at Ealing and Chorley—Sir E. Frankland's experiments—Frankland's doubts as to applicability on a large scale—Discredited on account of faulty experiments—Bailey Denton's experiments—Experimental filters at Clichy and Lawrence, Mass. —Attempts to increase quantitative results at Lawrence, Brockton, Framingham—Lawrence method of examination of soils—Effective size, uniformity coefficient—Water-retaining capacity, air capacity—Adoption of land filtration in Massachusetts —Clogging of the soil by humus—Hamburg experiments—Periods of rests—Methods of distribution—Experiments to explain the rapid removal of putrescible matter from sewage—Mechanical filtration — Chemical combination—Absorption — Colloidal theory—Capillary film—Oxygen required—Formation of a vacuum and oxygen drawn in —Formation of carbonic, nitric and sulphuric acids—Power of absorption exhausted—The rôle of bacteria and of oxygen—Necessity of periods of rest—Oxygen, carbon and nitrogen equilibrium—Nitric acid as an indicator—Life of land—Preliminary treatment of sewage—Attempts to increase quantities dealt with—Chemical and bacteriological nature of effluents. (Pp. 118-153.)

C. Artificial biological methods — Historical sketch — Suggested by Lawrence experiments—Repeated in London by Alexander Binnie, Santo Crimp and Dibdin; in Salford by Corbett—Stoddart's experiments. (Pp. 153-155.)

Contact Beds. (Pp. 155-187.)

Barking, Sutton, Manchester, Leeds—Hamburg experiments—Reactions whilst the bed is full—Putrescible matter very quickly separates—Importance of periods of resting — Absorption processes — Nomenclature — Oxygen consumed — Carbon dioxide formed—Artificial aeration —Development of heat—Importance of bacterial life—Enzymes—Selection of material for contact beds—Large surface area—Size of material—Porous nature of material—Lime salts in the material—Maturing of the filters—Weathering—Quantitative results—Structure—Sludging up—Regeneration —Preliminary treatment—Relation of sewage to sludging up of filters—Dibdin's slate beds—Automatic devices for filling and emptying the beds—Quantitative results—Qualitative action.

Percolating Filters. (Pp. 187-222.)

Advantages of continuous filters—Disadvantages—Lawrence (Mass.) experiments, 1890 — Waring, 1891 — Lowcock, 1892 — Corbett's sprayer, 1893 — Stoddart's distributor, 1898 — Stoddart's experiments, 1883 — Garfield's coal filter — Whittaker & Bryant rotating sprinkler at Accrington, 1898—Candy's rotating sprinkler at Reigate — Mather & Platt's rotating sprinkler — Jennings' rotating sprinkler—Scott-Moncrieff's motor driven sprinkler—Fiddian's water wheel distributor—Ham, Baker & Co.'s travelling water wheel distributor—Jennings' travelling distributor —Scott-Moncrieff's method — Ducat's method — Birmingham sprayer—Columbus sprayer—Structure of the filters—Hamburg experiments with fine surface layer—Reid's Hanley experiments with fine material—Danger of clogging with flocculent matter—Preliminary chemical treatment of the sewage—Hamburg filters—Preliminary experiments with syphons—Experiments with furrows—Furrowed filter at

Madeleine—Description of works constructed on the Hamburg system—Faulty adoption of this system. (Pp. 153-222.)

D. Degener's lignite method. (Pp. 223-227.)

CHAPTER IX.—THE DISINFECTION OF SEWAGE. (Pp. 228-244.)

Bacterial content and infectious nature of sewage—Fear of infecting rivers used for water supply—Importance of the population living on navigable streams—Measures for removing pathogenic sewage bacteria—Definition of the term "disinfection"—Bacillus coli as an indicator—Suspended matter a vehicle for bacteria—Septic tanks and pathogenic germs—Bacteria and broad irrigation—Bacteria and artificial biological filters—Disinfection by heat—Chemical disinfection—Hamburg comparative experiments—Chloride of lime as a disinfectant—Chemical tests of disinfection—Bacterial tests of disinfection—Chloride of lime neutralised by artificial filters—Continuous disinfection—Faulty action of chemicals on the suspended solids—Breaking up of suspended solids by septic action—Deodorisation of effluents from septic tanks.

CHAPTER X.—SUPERVISION AND INSPECTION OF SEWAGE DISPOSAL WORKS. (Pp. 245-255.)

Self-purification of streams—Inspection of works for the removal of suspended solids—Inspection of sedimentation tanks—Inspection of the streams—Desirability of uniform methods of chemical examination—Importance of opposing interests—The object of various chemical analyses—Physical appearance—Suspended solids—Chlorides—Tests for putrescibility (loss on ignition, oxygen absorption, dissolved oxygen, organic matter, Tidy's test, four hours' test, three minutes' test, incubator test, organic nitrogen, organic carbon, albuminoid nitrogen, ammonia, Hamburg putrescibility test)—Advantages of comparative tests as against absolute methods—Limits, standards, infection.

CHAPTER XI.—THE UTILITY AND COST OF THE VARIOUS METHODS OF SEWAGE TREATMENT. (Pp. 256-266.)

Works producing similar results are alone comparable—Local factors make comparisons difficult—Utility of detritus tanks, grit chambers, etc.—Results obtained by settlement and chemical precipitation—Importance of cost of sludge removal and experiments to reduce the quantity of sludge—Necessity of some treatment preliminary to biological purification—Sludge disposal and utilisation—Practical importance of artificial biological methods.

BIBLIOGRAPHY.

1. **Adam,** *Der gegenwärt. Stand der Abwässerfrage.* Brunswick, 1905.
2. *Annual Reports of the Rivers Department of the City of Manchester, 1901–1906.*
3. **Ashton,** *First Annual Report of the Manager of the Hacken Precipitation, Sludge Pressing and Destructor Plant and Rhodes Farm Sewage Filtration Area.* Bolton, 1902.
4. **Bailey Denton,** *Sewage Purification.* London, 1896.
5. **Baker,** *British Sewage Works.* New York, 1904.
6. **Barwise,** *The Purification of Sewage.* London, 1904.
7. **Baumeister,** *Technisches Gemeindeblatt,* i., 1899, p. 385.
8. —— *Städtisches Strassenwesen und Städtereinigung.* Berlin, 1890.
9. **Beckurts** and **Blasius,** *Zeitschr. für Hygiene,* vol. lv., 1906, p. 232.
10. **Binnie,** *The Surveyor,* vol. xx., 1901, p. 276.
11. **Bischoff,** *Technisches Gemeindeblatt,* v., 1902–3, p. 83.
12. **Bock** and **Schwarz,** *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen.* 3 Folge, vol. xix., 1900. Suppl., p. 148.
13. —— *loc. cit.,* vol. xxi., 1901. Suppl., p. 278.
14. **Bredtschneider,** *Gesundheits-Ingenieur,* xxviii., 1905, pp. 126, 146, 186.
15. —— *loc. cit.,* xxviii., 1905, p. 254.
16. —— *loc. cit.,* xxix., 1906, pp. 212, 239.
17. —— and **Thumm,** *Mitteilg. aus d. Kgl. Prüfungsanstalt f. Wasservers. u. Abwässerbeseitig. zu Berlin,* 1904, vol. iii.
18. **Busch,** *loc. cit.,* 1905, vol. v., p. 151.
19. **Büsing,** *Die Städtereinigung.* Stuttgart, 1897.
20. —— *Weyl's Handbuch der Hygiene,* vol. ii. Jena, 1894.
21. **Calmette,** *Revue d'Hygiène,* xxv., 1903, p. 233.
22. —— *Recherches sur l'épuration biolog. et chim. des eaux d'égout.* Paris, vol. i., 1905; vol. ii., 1907.
23. **Corfield** and **Parkes,** *The Treatment and Utilisation of Sewage.* 3rd edition. London, 1887.
24. **Crimp,** *Sewage Disposal Works.* 2nd edition. London, 1894.
25. **Darapsky,** *Gesundheit,* xxvii., 1902, p. 49.
26. **Degener,** *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen,* 3 Folge, vol. xv., 1898, p. 131.
27. **Dibdin,** *The Purification of Sewage and Water.* London, 1903.
28. **Digby** and **Shenton,** *The Surveyor,* vol. xxx., 1906, p. 653.
29. **Dunbar,** *Zeitschr. f. Hygiene,* vol. xii., 1892, p. 485.
30. —— *Deutsch. Vierteljahrschr. f. öffentl. Gesundheitspfl.,* vol. xxxi., 1899, p. 136.
31. —— *loc. cit.,* p. 625.
32. —— *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen.* 3 Folge, vol. xix., 1900; Suppl., p. 178.

33. **Dunbar**, *Zeitschr. d. Vereins d. deutsch. Zuckerindustrie*, vol. li., No. 551.

34. —— *Gesundheits-Ingenieur*, xxvi., 1903, p. 2.

35. —— *loc. cit.*, p. 536.

36. —— *loc. cit.*, p. 104, and xxviii., 1905, p. 535.

37. —— *Journal of the Royal Sanitary Institute*, vol. xxv., 1904, part iii., and *Gesundheits-Ingenieur*, xxviii., 1905, p. 157.

38. —— *Gesundheits-Ingenieur*, xxviii., 1905, p. 53.

39. —— *loc. cit.*, p. 249.

40. —— *Deutsch. Vierteljahrschr. f. öffentl. Gesundheitspfl.*, vol. xxxvii., 1905, p. 537.

41. —— *Gesundheits-Ingenieur*, xxix., 1906, p. 145.

42. —— *Zeitschr. d. Österr. Ing.- u. Architekten-Vereins*, 1906, Nos. 46 and 47.

43. **Dunbar** and **Korn**, *Gesundheits-Ingenieur*, xxvii., 1904, p. 17.

44. **Dunbar** and **Thumm**, *Beitrag zum derzeitigen Stand der Abwasserreinigungsfrage.* Munich, 1902.

45. **Dunbar** and **Zirn**, *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen*, 3 Folge, vol. xvi., 1898; Suppl., p. 137.

46. —— *loc. cit.*, xix., 1900, p. 216.

47. **Dünkelberg**, *Deutsch. Vierteljahrschr. f. öffentl. Gesundheitspfl.*, vol. vii., 1875, p. 24.

48. —— *Die Technik der Reinigung städtischer und industrieller Abwässer durch Berieselung und Filtration.* Brunswick, 1900.

49. **Dütschke**, *Offizieller Bericht über die IV. Hauptversammlung d. Deutsch. Medizinalbeamten-Vereins zu Heidelberg*, Sept. 8, 9, 1905. Berlin, 1905, pp. 72–113.

50. **Dziergowsky**, *Gesundheits-Ingenieur*, xxx., 1907, p. 1.

51. —— *loc. cit.*, p. 261.

52. **Emmerling**, *Gesundheit*, xxvii., 1902, p. 566.

53. **Farnsteiner**, **Buttenberg** and **Korn**, *Leitfaden für die chemische Untersuchung von Abwasser.* Munich, 1902.

54. **Fegebeutel**, *Die Kanalwasser- (Sewage) Bewässerung oder die flüssige Düngung der Felder.* Danzig, 1870.

55. **Fischer**, *Die chemische Technologie des Wassers.* Brunswick, 1878.

56. —— *Das Wasser.* 3rd edition. Berlin, 1902.

57. **Fowler**, *The Application of Chemical Analysis to the Study of the Biological Processes of Sewage Purification.* Lecture on 24th March 1904, Manchester.

58. **Fraenkel**, *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen*, 3 Folge, vol. xv., 1898; Suppl., p. 43.

59. **Franzius**, **Frühling**, **Schlichting** and **Sonne**, *Handbuch der Ingenieurwissenschaften*, vol. iii., part i., 2nd half; *Wasserversorgung und Entwässerung der Städte.* 3rd edition. Leipsic, 1893.

60. *Freiburg im Breisgau*, *Die Kanalisation, die Rieselfelder und deren Betrieb.* Freiburg i.-Br.

61. **Gaskell**, *The Work of the West Riding of Yorkshire Rivers Board: Statement.* Wakefield, 1903.

62. **Gärtner** and **Rubner**, *Arb. aus dem Kaiserl. Gesundheitsamt*, vol. xix., 1903, p. 458.

63. **Gärtner** and **Schümann**, *Deutsch. Vierteljahrschr. f. öffentl. Gesundheitspfl.*, vol. xxxv., 1903, p. 15.

64. **Geusen** and **Lisner**, *Die Kanalisationsanlagen Düsseldorfs. Sonderabdruck aus "Düsseldorf und seine Bauten."* Düsseldorf, 1904.

65. **Hagen**, *Die Berliner Rieselfelder.* Berlin.

66. **Haefcke**, *Städtische und Fabrikabwässer.* Leipsic, 1901.

67. **Holtz**, *Die Fürsorge für die Reinhaltung der Gewässer auf Grund der allgemeinen Verfügung vom 20 Febr. 1901.* Berlin, 1902.

68. **Höpfner** and **Paulmann**, *Mitteilg. aus der Kgl. Prüfungsanstalt f. Wasservers. u. Abwasserbeseitg. zu Berlin*, 1902, vol. iii., p. 146.

69. —— *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen*, 3 Folge, vol. xix., 1900, p. 130.

70. **Hüllmann,** *Deutsch. Vierteljahrschr. f. öffentl. Gesundheitspfl.*, vol. xix., 1887, p. 450.

71. **Imhoff,** *Mitteilg. aus der Kgl. Prüfungsanstalt f. Wasservers. u. Abwasserbeseitg. zu Berlin*, 1906, vol. vii., p. 1.

72. **Jenner,** *Zeitschr. f. Architektur und Ingenieurwesen*, vol. v., 1905.

73. **Johnson,** *Report on Sewage Purification at Columbus, Ohio.* November, 1905.

74. **Johnston,** *Jour. of the Royal Sanitary Institute*, vol. xxvii., 1906, No. 10.

75. **Jones** and **Travis,** *The Institution of Civil Engineers, Transactions*, Session 1905–6.

76. **Kammann** and **Carnwath,** *Gesundheits-Ingenieur*, xxix., 1906, p 665.

77. **Kattein** and **Lübbert,** *loc. cit.*, xxvi., 1903, p. 397.

78. —— and **Schoofs,** *Milchzeitung*, 1903, Nos. 7 and 8, p. 98.

79. **Keller,** *Zentralblatt der Bauverwaltung*, 1904, No. 20, p. 127.

80. **Kjeldahl,** *Zeitschr. f. analytische Chemie*, xxii., 1883, p. 366.

81. **Kleemann,** *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen*, 3 Folge, vol. xvi., 1898. Suppl., p. 47.

82 **König,** *Die Verunreinig. d. Gewässer.* Berlin, vols. i. and ii., 1899.

83. —— *Zeitschr. f. Untersuchg. d. Nahrungs- und Genussmittel*, iv., 1901, p. 193.

84. **Korn** and **Kammann,** *Gesundheits-Ingenieur*, xxx., 1907, p. 165.

85. **Kröhnke** and **Biltz,** *Hygienisch. Rundschau*, 1904, p. 401.

86. *Landesversicherung der Hansestädte, die vorbeugende Krankenpflege und Invalidenfürsorge.* Lübeck, 1904.

87. **Landois,** *Lehrbuch der Physiologie des Menschen.* 10th edition. Berlin, 1900.

88. *Die städt. Kläranlage für Schleusenwässer der Stadt Leipzig im Jahre 1905. Aus dem "Verwaltungsbericht der Stadt Leipzig,"* 1905.

89. **Lindley,** *Deutsch. Vierteljahrschr. f. öffentl. Gesundheitspfl.*, vol. xvi., 1884, p. 545.

90. —— *Denkschr. betr. Klärung der Abwässer von Barmen-Elberfeld*, Frankfort-on-the-Maine, 1901.

91. **Löffler,** *Vorlesungen über die geschichtliche Entwicklung der Lehre von den Bakterien.* Leipsic, 1887.

92. **Luckhardt,** *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätwessen*, 3 Folge, vol. xxi., 1901. Suppl., p. 262.

93. **Lübbert,** *Gesundheits-Ingenieur*, xxix., 1906, pp. 553, 585, 594. (Reply of Bredtschneider, *loc. cit.*, p. 591.)

94. **M'Donald,** *The Surveyor*, vol. xx. Supplement of Sept. 13, 1901.

95. **Mairich,** *Kanalisation der Stadt Guben.* Gotha, 1901.

96. **Marggraff,** *Bericht der Deputation für die städtischen Kanalisationswerke und Rieselfelder. Aus den "Verwaltungsberichten des Magistrats Berlin,"* 1903. 1905.

97. **Martin,** *The Sewage Problem.* London, 1905.

98. **Marx,** *Deutsch. Vierteljahrschr. f. öffentl. Gesundheitspfl.*, vol. xxix., 1897, p. 260.

99. **Merckel,** *Zeitschr. d. Vereins Deutscher Ingenieure*, 1906.

100. **Metzger,** *Technisches Gemeindeblatt*, iii., 1900–1, p. 228.

101. **Meyer** and **Metzger,** *Reisebericht über den derzeitigen Stand d. Abwasserreinigung mit bes. Berücksichtigung der Kläranlagen in England.* Bromberg, 1898.

102. **Moigno,** *Cosmos des Mondes*, 31, 1882, vol. i., p. 97.

103. **Monti,** *Archiv für Hygiene*, vol. xlvi., 1903, p. 121.

104. **Moore,** *Sanitary Engineering.* 2nd edition. London, 1901.

105. **Pasteur,** *Comptes rendus hebd. d. séances de l'académie des sciences*, vol. lvi., 1863, p. 1189.

106. **Pfuhl,** *Zeitschr. f. Hygiene*, vol. xii., 1892, p. 509.

107. **Proskauer** and **Elsner,** *Vierteljahrschr. f. gerichtl. Med. u. öffentl. Sanitätswesen*, 3 Folge, vol. xvi., 1898. Suppl., p. 157.

108. —— and **Zuelzer,** *Zeitschr. f. Hygiene*, vol. vii., 1889, p. 186.

109. **Rafter** and **Baker,** *Sewage Disposal in the United States.* London, 1894.

110. **Reich**, *Reinigung und Entwässerung Berlins, Anhang* I. Berlin, 1871.
111. **Reichle** and **Dost**, *Mitteilg. aus der Kgl. Prüfungsanstalt f. Wasservers. und Abwasserbeseitg. zu Berlin*, 1907, vol. viii., p. 146.
112. **Reincke**, *Das Medizinalwesen des hamburgischen Staates.* Hamburg, 1900.
113. **Reid**, *The Sanitary Record*, vol. xxxviii., 1906, p. 355.
114. —— *The Surveyor*, vol. xxxi., 1907, p. 274.
115. *Report of the Sewerage Commission of the City o, Baltimore*, 1906.
116. *Report on Sewage Disposal of the City of Leeds*, 1900, 1901, 1905, 1906.
117. *I.–III. Reports of the Rivers Pollution Commission.* London, 1866, 1870, 1871.
118. *Reports of the Royal Commission on Metropolitan Sewage Discharge.* London, 1884, 1885.
119. *I.–IV. Reports of the Royal Commission on Sewage Disposal.* London, 1901–4.
120. *Reports of the State Board of Health of Massachusetts, Boston*, No. 19, 1888 ; No. 20, 1889 ; No. 22, 1891 ; No. 23, 1892 ; No. 25, 1894 ; No. 26, 1895 ; No. 28, 1897 ; No. 31, 1900 ; No. 33, 1902 ; No. 34, 1903 ; No. 35, 1904 ; No. 36, 1905.
121. **Rideal**, *Sewage and the Bacterial Purification of Sewage.* 3rd edition. London, 1906.
122. **Ritzel**, *Die Wasserversorgung und die Entwässerung der Stadt Neustadt in Oberschlesien.* Berlin, 1900.
123. **Robinson**, *Sewerage and Sewage Disposal.* London, 1896.
124. —— and **Mellis**, *The Purification of Water-carried Sewage.* London, 1877.
125. **Rodewald**, *Zeitschr. f. physik. Chemie*, vol. xxxiii., 1900, p. 593.
126. **Roth** and **Bertschinger**, *Korrespondenzblatt für Schweizer Arzte*, 1900, No. 23.
127. **Rubner**, *Archiv für Hygiene*, vol. xlvi., 1903, p. 1.
128. **Sagasser**, *Wasser und Wegebau*, vol. iii., 1904, p. 29.
129. **Salomon**, *Die städtische Abwässerbeseitigung in Deutschland.* Jena, 1906. Vol. i., vol. ii. (Parts 1 and 2).
130. **Schloesing** and **Müntz**, *Comptes rendus hebd. d. séances de l'académie des sciences*, 1877, vol. lxxiv., p. 301 ; vol. lxxxv., p. 1018.
131. —— —— *loc. cit.*, 1878, vol. lxxxvi., p. 892.
132. —— —— *loc. cit.*, 1879, vol. lxxxix., p. 891.
133. **Schmidt**, *Der Hydrotekt*, 1902, p. 197.
134. —— *Zeitschr. f. Bauwesen*, vol. liii., 1903, p. 645.
135. **Schreiber**, *Archiv für Hygiene*, vol. xlv., 1902, p. 295.
136. **Schultz**, *Zeitschr. f. angewandte Chemie*, 1903, p. 833.
137. **Schumacher**, *Gesundheits-Ingenieur*, vol. xxviii., 1905, p. 361.
138. **Schury** and **Bujard**, *Mitteilg. aus der Kgl. Prüfungsanstalt f. Wasservers. und Abwasserbeseitg. zu Berlin*, 1907, vol. viii., p. 115.
139. **Schwarz**, *Gesundheits-Ingenieur*, vol. xxix., 1906, p. 773.
140. **Sedgwick**, **Winslow**, and **Phelps**, *Contributions from the San. Research Laboratory and Sewage Exp. Station of the Mass. Inst. of Technology.* Boston, vol. ii., 1906.
141. *Sewage Disposal and Apparatus.*—The Septic Tank Company, Ltd., London, Westminster.
142. **O'Shaughnessy**, "The Behaviour of Colloids in Sewage," *Journ. of Soc. o, Chem. Ind.*, vol. xxv., 1906, p. 719.
143. **Spitta**, *Archiv für Hygiene*, vol. xlvi., 1903, p. 64.
144. —— and **Weldert**, *Mitteilg. aus der Kgl. Prüfungsanstalt f. Wasservers. u. Abwässerbeseitg. zu Berlin*, 1906, vol. vi., p. 160.
145. **Steuernagel**, *Technisches Gemeindeblatt*, iii., 1900–1, p. 305.
146. —— *Mitteilg. aus der Kgl. Prüfungsanstalt f. Wasservers. u. Abwässerbeseitg. zu Berlin*, 1904, vol. iv., p. 1.
147. *Das städtische Tiefbauwesen zu Frankfurt am M.* Frankfort on the Maine, 1903.
148. **Tiemann - Gärtner**, *Handbuch der Untersuchung und Beurteilung der Wässer.* 4th edition. Brunswick, 1895.
149. **Varrentrapp**, *Entwässerung der Städte.* Berlin, 1868.
150. **Virchow**, *Berliner klinisch. Wochenschrift*, 1893, p. 153.

151. **Waring**, *Modern Methods of Sewage Disposal.* New York, 1896.

152. **Warington**, *Journ. of the Chem. Soc.*, vol. xxxiii., 1878, p. 44 ; and *Chem. News*, vol. xxxv., 1877, p. 263.

153. **Watson**, *The Purification of Sewage, with Special Reference to the Works of the Birmingham Tame and Rea District Drainage Board*, Tyburn, near Birmingham, 1903.

154. **Watson**, *Sludge Treatment in Relation to Sewage Disposal.* A Paper read at the Annual Meeting of the Incorporated Association of Municipal and County Engineers, held in London, June 28, 29, and 30, 1906.

155. **Weigelt**, *Vorschriften für die Entnahme und Untersuchung von Abwässern und Fischwässern.* Berlin, 1900.

156. —— *L'Assainissement et le Repeuplement des Rivières.* Berlin, 1904.

157. **Weyl**, *Gesundheits-Ingenieur*, xxiv., 1901, p. 125.

158. —— *loc. cit.*, xxv., 1902, p. 397.

159. —— *Technisches Gemeindeblatt*, vi., 1903–4, p. 213.

160. —— *Die Assanierung von Köln.* Leipsic, 1906.

161. **Wilson**, *Journ. of the San. Inst.*, vol. xxiv., part 3, 1904.

162. **Wimmer**, *Die verschiedenen Verfahren zur Schmutzwasserreinigung unter bes. Berücksichtigung des Kostenpunktes.* Dresden, 1906.

163. **Winogradsky**, *Ann. de l'Inst. Pasteur*, xl., 1890, p 213.

164. **Winslow**, *Journ. of the Association of Eng. Soc.*, vol. xxxiv., No. 6.

165. **Wollny**, *Die Zersetzung der organischen Stoffe und die Humusbildung.* Heidelberg, 1897.

166. **Worth** and **Crimp**, *On the Main Drainage of London.* London, 1897.

SUPPLEMENT.

167. **Favre**, *Gesundheits-Ingenieur*, xxx., 1907, p. 809.

LIST OF ILLUSTRATIONS.

FIG. PAGE
1. Berlin Detritus Tank 43
2. Detritus Tank adopted in England. Longitudinal Section . . . 43
3. ,, ,, (Ohrdruf) 44
4. ,, ,, (General Town-Cleansing Co.) 44
5. Schneppendahl's System of Sieves and Detritus Tanks . . . 44
6. Detritus Tank (Cologne) 45
7. Grab Dredger used at Birmingham 45
8. Sewage Sieve (Wayne) 48
9. ,, ,, (White Plains) 48
10. Perforated Metallic Basket (Rhode Island) 48
11. Screen with Automatic Cleansing Apparatus (Bromberg). Longitudinal Section 49
12. ,, ,, ,, ,, Cross Section . 50
13. ,, ,, ,, ,, Plan . . 50
14. Screen with Automatic Rakes (Clichy, Paris) 51
15. ,, ,, ,, (Manchester) 51
16. Riensch's Medium Screen. Longitudinal Section 52
17. Riensch's Fine Screen 53
18. Riensch's Medium Screen. Plan 53
19. Winged Screen. Longitudinal Section 54
20. ,, ,, (Allenstein) 54
21. ,, ,, (Allenstein) 54
22. Revolving Screen, John Smith & Co., Carshalton 55
23. ,, ,, ,, ... 55
24. Screening Apparatus (Hamburg) 56
25. Bars of Hamburg Screen 56
26. Screening Apparatus (Croydon) 57
27. ,, ,, ,, ... 57
28. Friedrich's Screening Apparatus. Elevation 58
29. ,, ,, ,, Plan 58
30. Riensch's Disc Sieve 59
31. ,, ,, ... 60
32. ,, ,, ... 60
33. Riensch's Experimental Works (Dresden). Longitudinal Section . . 61
34. ,, ,, ,, Plan 61
35. Screening Apparatus by Joerning and Sauter 62
36. Kremer's Grease Extractor (Frankfort) 63
37. ,, ,, ... 63
38. ,, ,, ... 64
39. Apparatus for Emptying Settling Tanks 66
40. Horseshoe Arrangement of Tanks 67

FIG. PAGE
41. Sedimentation Tanks adopted in England. Longitudinal Section . . 67
42. ,, ,, with Cross Walls 67
43. Arrangement of Sedimentation Tanks 67
44. Good and Bad Construction of the Bottom of Sedimentation Tanks, according to Steuernagel 68
45. Experimental Settling Tank (Cologne). Longitudinal Section . . 69
46. Action of Pump Well at Cologne with various Sewage Velocities . . 70
47. Flow of Sewage through Tanks on Cold Days, according to Schmidt . . 72
48. ,, ,, ,, Warm ,, ,, . . 72
49. Müller and Nahnsen Tank (Halle) 73
50. Kniebühler's Tank (Dortmund). Cross Section 73
51. ,, ,, ,, ... 74
52. ,, ,, ,, ... 74
53. Mairich's Tanks (Neustadt, Upper Silesia) 74
54. Mairich's Tank (Stargard) 75
55. ,, ,, (Guben) Plan 75
56. ,, ,, ,, Cross Section 76
57. Watson's Birmingham Separator 76
58. Dervaux's Apparatus with Conical Surfaces 77
59. Fidler's Sludge Collector (Ham, Baker & Co.) 78
60. ,, ,, for Rectangular Shallow Tanks (Ham, Baker & Co.). 79
61. Removing Sludge from Sedimentation Tanks, Old Methods (Bolton) . . 79
62. Ashton's Apparatus for removing Sludge from Sedimentation Tanks (Bolton). 80
63. Rothe-Röckner Tower 81
64. Fosse Mouras. La vidangeuse automatique 82
65. ,, ,, (Bordeaux) 83
66. Travis' Hydrolytic Tank Model 90
67. Remains of a Guinea-pig after three weeks in Septic Tank . . . 92
68. Ridge and Furrow Irrigation. Cross Section 103
69. ,, ,, ,, Bird's-eye View 103
70. ,, ,, ,, Plan 104
71. Bed Irrigation. Cross Section. 104
72. Irrigation on Terraces. Cross Section 105
73. Gerson's System of Irrigation. Plan 105
74. Wulsch's System of Spraying Sewage with Hose Pipe 106
75. Subsoil Irrigation. Protected Drain 106
76. Longitudinal Drainage. Plan 108
77. Diagonal Drainage. Plan 108
78. Flooded Irrigation Farm 112
79. Construction of Sewers to exclude Subsoil Water (Brockton) . . . 124
80. ,, ,, ,, ,, ... 124
81. Intermittent Filtration Works (Brockton) 125
82. Distribution of Sewage on Filters 125
83. Furrows on the Surface of Filters 126
84. Intermittent Filter in Winter (Framingham) 130
85. Size of Material in Filter No. 6. 133
86. Size of Material in Filters No. 5 and No. 16 134
87. Purification effected by Intermittent Filtration 139
88. Absorption of Albumen by Sterile Clinker-Filter 161
89. Hamburg Method of Washing Contact Beds 178
90. Adams' Automatic Feed for Contact Beds. Bed Filling . . . 185
91. ,, ,, ,, Bed Full . . . 185
92. Double Contact Beds fitted with Adams' Automatic Feed. Longitudinal Section 185
93. ,, ,, ,, Plan . . 186
94. Waring's Trickling Filter 190
95. Lowcock's ,, ,, ... 191

FIG. PAGE
96. Stoddart's Experiments . . . 192
97. Biological Filters on Stoddart's System . . . 193
98. Stoddart's Distributor . . . 193
99. ,, Biological Filter. Cross Section . . . 194
100. Corbett's Sewage Distributor for Intermittent Action . . . 194
101. Whittaker & Bryant Sprinkler at Accrington . . . 196
102. ,, ,, Biological Filters at Accrington . . . 196
103. Aeration and Drain Pipes at the Bottom of Accrington Filters . . . 197
104. Accrington Sprinkler. Mercury Seal . . . 197
105. Candy Sprinkler at Reigate . . . 197
106. Apparatus for feeding Candy Sprinkler intermittently at Leeds . . . 198
107. Apparatus for Measuring Charge and Feeding Sprinklers intermittently. Mather & Platt . . . 198
108. Mather & Platt Sprinkler with open Channels . . . 199
109. ,, ,, ,, driven by Turbines . . . 199
110. ,, ,, ,, electrically driven (Chichester) . . . 200
111. Birmingham Sprinklers . . . 200
112. Jennings' Rotating Sprinkler with Syphonic Feed . . . 201
113. Method of Support for Jennings' Sprinkler . . . 201
114. Scott-Moncrieff Distributor, Motor-driven (Birmingham) . . . 202
115. Fiddian Distributor (Enfield) . . . 202
116. ,, ,, in course of erection . . . 203
117. Wilcox & Raikes' Distributor for Rectangular Filters, motor-driven . . . 203
118. Ham, Baker & Co. Distributor. Fiddian's Principle applied to Rectangular Filters (Bolton) . . . 204
119. Jennings' Distributor for Rectangular Filters . . . 204
120. 121. } Scott-Moncrieff's Cultivation Tank and Biological Filter . . . 205
122. Ducat's Biological Filter with Heating Arrangement . . . 205
123. Ducat's Biological Filter, showing Method of Aeration and Grading of Material 206
124. Gjers & Harrison Spray Jet, as used by Corbett at Salford . . . 206
125. Gjers & Harrison Fixed Spray Jet in Action . . . 206
126. Ham, Baker & Co. Sprayer at Birmingham . . . 206
127. Birmingham Filters. Cross Section . . . 207
128. ,, ,, Bird's-eye View . . . 207
129. Columbus Sprayer in Winter . . . 208
130. ,, ,, . . . 208
131. ,, ,, in Action . . . 208
132. Hamburg Trickling Filters (Andreasberg) . . . 213
133. Calmette's Filters (Madeleine) . . . 214
134. Hamburg Trickling Filter (Gross-Hansdorf). Cross Section . . . 214
135. ,, ,, ,, Plan . . . 215
136. General View of Dimensions of Biological Sewage Works for a Sanatorium . 215
137. Hamburg Trickling Filter (Oderberg). Cross Section . . . 216
138. ,, ,, ,, Longitudinal Section . . . 217
139. ,, ,, (Poppenbüttel). Longitudinal Section . . . 218
140. Large Hamburg Filters. Plan . . . 218
141. ,, ,, Cross Section and Longitudinal Section . . . 219
142. Lignite Method, Tegel Works . . . 224
143. ,, ,, Plan . . . 224
144. ,, Tower at Tegel . . . 225
145. Sludge Press . . . 259
146. Pumping Sludge to Sludge Beds (Birmingham) . . . 264
147. Burying Sludge (Birmingham) . . . 264

PRINCIPLES OF SEWAGE TREATMENT.

PART I.—HISTORICAL DEVELOPMENT OF THE SEWAGE PROBLEM.

CHAPTER I.

GROWTH OF RIVER POLLUTION.

Accumulation of Filth.—Until well into the nineteenth century the sewage problem was one of which little or nothing was heard. Every man disposed of his filth as best he could. Cesspools for fæcal matter were either recommended or tolerated by the authorities, but it was generally left to the individual householder to dispose of the contents. Fæcal matter and domestic refuse were allowed to accumulate near the dwellings, either above or below ground, and to sink into the soil; where this was not possible it was carted away on to the land. This gave rise to very objectionable conditions in the thickly populated districts of large towns.

Water-closets.—In 1810 the water-closet was invented, or, more strictly speaking, re-invented. This apparently harmless mechanism has been the cause of changes which could not have been suspected at that time. At first it was only slowly introduced, but it soon commenced to rapidly increase in favour, and about fifty years ago its use was considered so important that its introduction into the gigantic city, London, was made obligatory. No one had any idea of the consequences which would thus be conjured up, and it was thought that the contents of water-closets could be emptied into underground cesspools from which they could be carted away. Householders, however, found it more convenient and less costly to provide these cesspools with overflows leading into the street drains. The existing drains were not intended to receive foul water, and were unsuitable for the purpose, being in places open along the streets. The state of things which arose from the putrefying fæcal matter lying in the streets became unbearable, but the imposition of penalties for using rain-water drains to convey sewage had no good effect; in fact, cesspools were often done away with, and the water-closets connected directly with the drains. From the hygienic point of view this was perhaps a step in the proper direction.

The number of water-closets continued to increase, for property owners had learned to appreciate that which allowed them to get rid of all kinds of filth before putrefaction set in, and they no longer thought of giving up the advantages they thus reaped.

The nuisance was thus removed from private properties into the public streets. This second stage of the sewage disposal problem was so generally felt to be obnoxious that underground sewers had to be constructed. For years these were laid upon no system except that of reaching a public watercourse by the shortest route. The evil results of this want of system cannot be further described here. The new methods were, however, so successful in removing evil smells from the streets that water-closets and the water-carriage system of sewerage were generally adopted in many English towns, and at various points within the precincts of the towns these foul-water sewers emptied into the rivers. The rivers had previously been able to deal with the filth which reached them *viâ* the street drains; but with the increase in this filth, consequent upon the laying of these new sewers, complaints were everywhere made of the polluted condition of the streams. Thus arose the third stage of the sewage problem, which is that of to-day.

Pollution of English Rivers.—The consequences of this excessive pollution were first felt in the narrow thickly-populated English valleys, especially where, as in London, the water supply was derived from the rivers. A typical case of this excessive pollution may be here shortly described. Three main parallel valleys cross the West Riding of Yorkshire from east to west, those of the Wharfe, the Aire, and the Calder, and it has been calculated that out of each 100 parts of rain-water falling on the surface of nearly two million acres, 80 parts find their outlet by the Humber. Since the middle of the eighteenth century there has been a gradual, but steady, increase in the population and in the manufactures; and, although all kinds of domestic and trade refuse found its way into the streams, there was no noticeable pollution until about the middle of the nineteenth century. At this time, however, there was a great increase in manufacturing operations and in the population which came to work in the factories, which were made larger and more numerous. Salmon and trout were caught in these rivers as late as 1850, but these soon became extinct, and a few years later the coarse fish, first the dace, then the roach, also disappeared. There was little or no opposition to the growing pollution. The general impression seemed to be that the use of rivers was to carry away sewage and refuse. A population of over two millions, of which two-thirds were engaged in industrial pursuits, emptied the whole of its refuse into some of these comparatively small streams, which consequently became in summer "a boiling stinking mass," as is recorded in official documents. The evidence of one dwelling in this neighbourhood is characteristic; "one night," he says, "we had an escape of gas in one of our bedrooms. We opened the windows to let it out, but the stench from outside was so intolerable that we shut down the windows, and preferred having the gas to having the stench from the canal." Children amused themselves by setting the gas which floated on the canal alight. Blue flames arose to a height of six feet, enveloping barges in their course, as they ran like gunpowder a distance of a hundred yards along the water. The carcases of animals poisoned the air as they floated down the rivers or were stranded on the banks. It was no one's business to remove them. One lock at Manchester had nineteen dead dogs in it; more than forty dead dogs, when there was a flood, would pass Stanley Ferry on the Calder in a single day. In the leather trade of Leeds and district several million hides were dealt with yearly. All the refuse which was produced in this trade which could possibly be washed into the river found its way there. Besides the tanneries, woollen mills, dye works, paper works, and many other branches of industry sprang up, and the large volume of putrescible sewage which they produced was allowed to flow into the river. The quantity of ashes and slag which was yearly tipped into the Aire and Calder has been estimated at thousands of tons. Earthenware manufactories, as well as brick and metal works, threw their solid refuse into the rivers; when buildings were pulled down the old material was tipped into the rivers; soil, stones, clay from quarries and mines, road grit and all the filth which was collected from the streets, as well as all the sewage of houses and of the most varied manufactories, altogether some millions of cubic yards daily, went into the comparatively small rivers, which thus became not only foul-smelling and inky, but also so sludged up that their flow was interfered with and their banks overflowed. During the official inquiries the manufacturers rightly maintained that the river water was spoiled for their purposes by the domestic sewage, but they themselves allowed all the refuse from their factories to flow into the rivers, and thus made matters worse for those situated lower down on the banks of the same stream. No one, however, felt constrained to have any consideration for those lower down the stream. Even to-day, in spite of the most vigorous action on the part of the supervising authorities, all the consequences of such bad management have not been removed.

Pollution of the Seine.—The Seine below Paris was also in a very bad state, as may be judged from the following description, which dates from the time when all the sewage of Paris was allowed to flow into the river in a crude state. Above the bridge at Asnières the river bed is covered with white sand, fish are abundant in the water, and the banks are rich with vegetation. From the point at which the large sewer from Clichy enters the river all this is changed. A stream of black water, covered with grease, corks, hair, carcases, and other filth, moves along the river bed. A grey sludge containing organic matter accumulates along the right bank and gives rise to foul-smelling islands. Lower down, this sludge covers the whole bed of the river, ferments, and gives rise to gases which rise as bubbles and burst at the surface. In the hot seasons these bubbles are often to be seen a yard or a yard and a half in diameter; they raise the stinking sludge along with them, and fish life and vegetation are entirely absent.

Pollution of the Emscher.—Although for centuries refuse has been allowed to enter the German rivers it is only during the nineteenth century that pollution has been at all evident. Manufacturing refuse has been the main cause of the pollution and domestic sewage in a less degree. In a few of the smaller streams conditions are to be found which approach those already described for English rivers. The most interesting example in Germany of a rapid increase in pollution is furnished by the valley of the Emscher. This valley, according to a publication of Keller, is in the centre of the Rhine-Westphalian industrial district, between the watersheds of the rivers Ruhr and Lippe, and has a drainage area of about 300 square miles. The rapid fall of the Emscher in its higher reaches was utilised by means of eight mills and six weirs. For centuries complaint has been made of the poor drainage which the river afforded, with the consequent floods and waterlogging of the neighbouring land, but no mention was made of pollution. About 1850 the coal industry began to grow. Blast furnaces, steel works, foundries, engineering works, etc., were erected, and the previously thinly populated district quickly became the most thickly populated in Germany. In 1880 the population was half a million, which became practically trebled during the next twenty years. The ground commenced to sink in consequence of the coal mining operations; polder works and water engines were erected, but did not successfully attain the objects for which they were intended. All the tributaries of the Emscher became so polluted that they were like open sewers. The river water could no longer be used for agricultural purposes on account of the large amount of salts which it contained as a result of industrial operations. Complaints were made on this account, and also on account of the large volumes of water abstracted from the Ruhr and discharged into the Emscher valley.

In 1889 the State appointed an Emscher Regulation Commission, which spent about £300,000 in draining marshy land. The result was not satisfactory. Sewage purification works could not be carried out in places where they were necessary on account of want of fall. For example, twenty-seven out of fifty-six hospitals emptied their sewage direct into the stream and the remainder had only inefficient works. The collieries were provided with settling tanks for their coal-washing waters, but these were mostly full of sludge. In times of flood, filth of all kinds was spread about the district. It was regarded as a consequence of this state of things that dysentery and typhus repeatedly broke out seriously in the district.

The conditions which exist in the Emscher valley are not singular in Germany. Various streams might be mentioned which cannot be distinguished from sewers by their contents. They are putrefying, fermenting masses, or are either inky black or some other colour, on account of the manufacturing wastes which they contain. However, these conditions in Germany are neither so common nor so serious as in England. The same may be said of all other civilised countries. In comparison with England, where the majority of the rivers were, and partly still are, seriously polluted, Germany and all other countries are at present only just showing the first signs of approach to such conditions, as is seen in the fact that they may be observed here and there. Unmistakably, however, pollution is making rapid strides even in the comparatively much larger rivers of Germany, strides which keep pace with the rapid growth of large towns and the unexampled industrial development.

CHAPTER II.

LEGAL MEASURES TAKEN BY CENTRAL AND LOCAL AUTHORITIES.

Removal of Filth from Towns. — The incredible results of the systematic pollution of the English rivers were at first borne with exemplary toleration. Complaints were made here and there, and official inquiries held; but matters were allowed to drift from bad to worse. In 1865, however, complaints became so general that the Government appointed a Royal Commission to inquire into the pollution of rivers, and from that date the subject of river pollution has been continually before the authorities. Commissions have been appointed by Parliament, local authorities, and scientific associations, with the result that innumerable measures have been taken to combat the problem of river pollution.

It is impossible here to enumerate all these measures, and we must be content to deal with the question only so far as is necessary to indicate the difficulties which uniform legislation encounters, and to show the uselessness of legislation which demands the performance of technical impossibilities.

River Pollution Permitted.—Previous to 1850 all reports and enactments show that their main object was to minimise the pollution within the towns and in the immediate neighbourhood of human habitations. The street drains, already referred to, made their surroundings pestiferous. They were regarded as being responsible for fevers and other diseases, and it was considered inadmissible to aggravate the already bad condition of the poorer classes through whose districts these filthy drains generally passed. No wonder, then, that the experts called in by the Government declared that it was less dangerous to discharge the filth direct into the rivers than to allow it to accumulate in thickly populated districts. An Act of Parliament was passed therefore in 1847, giving local authorities the power to discharge their sewage direct into rivers or into the sea. At the same time it was pointed out that the sewage might be utilised for the irrigation of land.

In 1854 the highest public health authority in England also regarded *it as better* to admit sewage to the nearest water-course than to allow it to accumulate near dwellings, and not until 1857 did the experts of this authority recommend the removal of suspended matter or the deodorisation of sewage before its admission to the streams.

It will be seen, therefore, that the present-day opinions have not always been held with regard to the purity of our rivers. Public opinion has developed step by step with the gradually increasing adoption of water-closets and the water-carriage system of sewerage.

River Pollution Prohibited. — In 1858 the pollution of rivers in England was legally prohibited, or at any rate it was made clear that towns could not pollute rivers to the detriment of the interests of others. An Act of 1861 required sewage to be purified and freed from fæcal and other putrescible matters before being discharged to the streams. The large towns of England—Birmingham, Huddersfield, Nottingham, and Sheffield—even petitioned for the prohibition of the discharge of unpurified sewage into the streams. But the enactments up to this time had been of no avail; they were loosely administered, and the condition of the rivers became worse from year to year.

Hence, in 1865, the Government appointed the Commission mentioned above. The reports of this Commission are among the most interesting and historically the most valuable material which exists on the subject of river pollution. The above sketch of the conditions in the West Riding of Yorkshire is taken from these reports. In 1868 this Commission was dissolved and another took its place—the Rivers Pollution Prevention Commission, of which Sir Edward Frankland was a member. The question of sewage purification, as we shall see later, was very thoroughly dealt with, and the contributions to this subject are among the most valuable which have ever been made.

One instruction which this Commission received is specially worthy of note. It runs:—"Although it may be taken as proved generally that there is a wide-spread and serious pollution of rivers, both from town sewage and the refuse of mines and manufactories, and that town sewage may be turned to profitable account as a manure, there is not sufficient evidence to show that any measure absolutely prohibiting the discharge of such refuse into rivers, or absolutely compelling town authorities to carry it on the lands, might not be remedying one evil at the cost of an evil still more serious, in the shape of injury to health and damage to manufactures."

In 1869 a Commission was appointed to deal with the disposal of London sewage. This Commission is mentioned here only because it was as a result of its activity that the English Central Authority, the Local Government Board, was founded (1871). This Board has exercised a somewhat fatal influence on the development of the problems of sewage disposal and river pollution down to very recent times, not for want of good intentions, but rather as a result of its bureaucratic constitution.

The Public Health Act of 1872 is specially important. It made possible the formation of Boards for preventing river pollution, and thus gave the first opportunity to make a practical attempt at a solution of the problem, an opportunity which was only utilised at a much later date.

An Amendment Act was passed in 1875 and the Rivers Pollution Prevention Act came into force in 1876. These two Acts embodied all previous legislation on the subject and at the time raised great hopes of the dawn of a new era. The 1875 Act stipulated that the Local Government Board should only sanction the raising of loans for purposes of sewage disposal after the schemes had been favourably reported upon by an inspector of that Board who had held a local inquiry. It further stipulated that all town authorities should remove solids and fæcal matter from sewage, to such an extent that no nuisance should be caused, before its discharge into canals, rivers, lakes, or the sea. The Act of 1876 gave the Local Government Board power to require land treatment in all cases. For reasons which will be given later, these two Acts have not been of very great utility.

All Commissions which had dealt with the problem of sewage disposal were unanimous in recommending the establishment of a special authority to take charge of all problems connected with river pollution. In one Commission opinion was so far divided that one member recommended a local authority, while the other two advised the establishment of a central authority, on the ground that a local authority might be hindered in the carrying out of its duties by personal influence.

Ineffectiveness of Legislative Measures.—Although all these Commissions, especially the Royal Commissions of 1865 and 1868, had shown, in the most convincing and drastic manner, that the awful condition of the rivers need not continue, the people still remained unmoved and not sufficiently anxious for legislation. The manufacturers had considerable influence and obtained the insertion of such clauses into the Acts of Parliament as to make these practically inoperative. The main Act, the Rivers Pollution Prevention Act of 1876, does prohibit the throwing of solid matters into the streams and the pollution of streams by sewage matter and manufacturing refuse, but it is necessary to prove that the solid matter is either putrid or putrescible, or that it pollutes the waters of the stream, or that it is thrown in in such quantities as to interfere with the due flow of the stream. Proceedings could only be taken by sanitary authorities against manufacturers and colliery proprietors with the express sanction of the Local Government Board. It was soon seen that the Act was only a dead letter, and that no more could be achieved by its aid than by an Act of 1388, whereby the discharge of animal refuse into rivers was prohibited under a penalty of £20.

Progress of River Purification.—In 1888 efforts were made to utilise the rights conferred by the Public Health Act of 1872 and to form Joint Committees, having representatives from all sanitary authorities bordering on a specific river. Such Joint Committees were entrusted with the *powers of a* sanitary authority so far as was necessary for the administration of the Rivers Pollution Prevention Act of 1876. The Mersey and Irwell Joint Committee was formed in 1891 as a result of a petition from the County Councils of Lancashire and Cheshire. Leeds and Bradford presented a similar petition for the formation of a Joint Committee for the districts of the West Riding in 1890; but local interests, which stood in the way, were not overcome for some years. The Mersey and Irwell Joint Committee soon recognised that little could be attained with the existing legislation, that indeed the various sub-clauses of the Act of 1876 made progress impossible. The Committee, therefore, promoted a Bill in Parliament, an example which was soon followed by the West Riding Joint Committee, which had been formed in the meantime. The Mersey and Irwell Act was passed in 1892, and in July 1893 a Provisional Order was granted for the West Riding, by which a Joint Committee was formed, consisting of thirty local representatives. The West Riding of Yorkshire Rivers Act followed in 1894. Although not all that could be desired, this Act is undoubtedly an advance upon previous legislation. It gives the Joint Committee special powers against the pollution of streams by solid matters. No action can, however, be taken against the putting into streams of sand, gravel, or other natural deposit which shall have flowed from or been deposited by the current of the stream, unless it can be shown that the due flow of the stream is interfered with. The pollution of streams by sewage matter and liquid manufacturing refuse is also prohibited; but in the latter case proceedings can only be taken with the sanction of the Local Government Board and after certain preliminary warnings have been given to the manufacturer. Further, the Local Government Board shall only give consent to proceedings being taken by the Rivers Board, if, after due inquiry, the Rivers Board and the Local Government Board are satisfied that, having regard to the reasonableness of the cost and the effect on the industry or trade in question, means are available for rendering the polluting liquid harmless and that no material injury will be inflicted by such proceedings on the interests of such industry or trade. The value of the Act as a means of suppressing nuisances is greatly diminished by such clauses, but a special Act, the Factory Act, does contain some useful clauses. In a statement as to the work of the West Riding Rivers Board during the first ten years of its existence, Mr. Charles G. Milnes Gaskell, the chairman, mentions that the practice of throwing solid refuse into the streams has been virtually stopped, with the exception of the sludging of mill dams. At the beginning of this period there were 126 sewage works in the Riding, many of which were inefficient, whereas ten years later the number had risen to 267, all of which were more or less efficient. Many of the old works had been remodelled or enlarged, and 72 projects for new works or extensions were awaiting the sanction of the Local Government Board. In 1893 there were only 155 out of 1944 mills where some measures had been adopted for the prevention of the pollution of the streams by the discharge of trade refuse. The works at these mills were mostly small tanks, and the majority of them were seldom, if ever, cleaned out. Other 966 mills discharged their effluents into the stream without treatment and the remainder into public sewers. In 1902, out of a total of 1983 mills, only 422 were discharging refuse without treatment to the streams, 542 possessed purification works, and the remainder discharged to the public sewers. In 1893, of the largest towns of the Riding, only Leeds and Sheffield attempted to treat the whole of their sewage, whilst Bradford dealt with less than one-twelfth. In 1904 all the large towns were treating their sewage at least to the extent of keeping one-half of the noxious matters out of the rivers.

Many of the manufacturers who have constructed purification works find it profitable to have done so. One papermaker has effected a saving of £500 a year, a blanket manufacturer £1000 a year, and a colliery proprietor similarly recovers 300 tons of coal a fortnight which previously went into the river.

These results have not been achieved without difficulty. The whole population, including the manufacturers, is in sympathy with the work of the Rivers Board, but each individual wishes to remain undisturbed. Excuses for inaction, all the dilatory pleas that lawyers can suggest, have met the Board at every turn. The representatives of various industries have formed an association, the aim of which has been to defeat the objects of the Rivers Board so far as its individual members are concerned.

What has been said of the West Riding Rivers Board applies equally to the other Rivers Boards. In 1893 the mills of Lancashire and Cheshire only possessed 45 purification works, whereas in 1906 the number had risen to 268. In 1892 only 27 towns possessed sewage works; in 1906, 80 towns were treating their sewage.

In 1898 another Royal Commission was appointed. There were two main questions with which it had to deal. Firstly, what method or methods of treating and disposing of sewage (including any liquid from any factory, or manufacturing process) may properly be adopted, consistently with due regard for the requirements of the existing law, for the protection of the public health, and for the economical and efficient discharge of the duties of local authorities? and, secondly, if more than one method may be so adopted, by what rules, in relation to the nature or volume of sewage, or the population to be served, or other varying circumstances or requirements, should the particular method of treatment and disposal to be adopted be determined?

Land Irrigation and Pure Effluents.—The main cause for the appointment of this Commission was the fact that the Local Government Board required a final land treatment in all projects for sewage works, which had to be submitted to them, if the local authority proposed to raise a loan for *the purpose of* carrying out the works, although in the meantime methods had been devised which were said to yield results equal to land treatment. Many towns found it impossible to obtain sufficient land to meet the requirements of the Local Government Board, even in cases where they were prepared to pay enormous sums of money for it. The landowners and the inhabitants were generally averse to the proposed land being used for purposes of sewage disposal, and very often suitable land was not available within a reasonable distance of the town. This position of affairs amounted almost to a calamity for some of the large towns of England. The Commissioners therefore hastened to issue an Interim Report (1901), in which they dealt with the questions: (1) Are some sorts of land unsuitable for the purification of sewage? (2) is it practicable uniformly to produce by artificial processes alone an effluent which shall not putrefy, and so create a nuisance in the stream into which it is discharged? and (3) what means should be adopted for securing the better protection of our rivers?

This Report demonstrates that the requirements of the Local Government Board had been justified by the historical development of things.

The Commission appointed in 1857 had declared that the proper method of purifying sewage was to distribute it on land, and that only in this manner could the pollution of rivers be prevented. The 1868 Commission, which issued in all five reports up to the year 1874, had also declared that land treatment was the only suitable method of rendering sewage non-putrescible, and that all other methods were only suitable for removing the solids in suspension and should thus only be regarded as palliatives. The 1882 Commission likewise declared that land treatment was the only solution of the problem, and that even for towns in a position as favourable as London, for disposing of its sewage into a large river, it was the only method worth considering. The Local Government Board had therefore adopted the standpoint expressed so forcibly by these Commissions and had only deviated from it in exceptional cases.

The Report goes on to deal with artificial biological methods which had been devised in the meantime and to discuss the question as to whether these had rendered land treatment superfluous. It also states that the then position of science only placed chemical methods of examination at the disposal of the earlier Commissions, whereas now bacteriological methods have been so developed as to be of use and importance.

The Commissioners conclude that peat and stiff clay are not suitable for sewage purification. Where only such soils are available, the work of purification can only be performed by the surface layer of humus or other porous soil; and in cases where this surface layer is not more than, say, six inches thick, such large areas of land would be necessary as to render a scheme of land treatment impracticable. This is an admission on the part of the Commission that cases do occur in which land treatment should not be insisted upon.

As to whether methods are available which render land treatment superfluous, the Commissioners state that they are convinced that by means of artificial biological processes not followed by land treatment effluents may be obtained from sewage and mixtures of sewage with trade refuse which are no longer putrescible, and which, judged by the usual methods, are satisfactory enough to be discharged into streams without fear of causing a nuisance. There are cases, therefore, in which the Local Government Board may properly, with certain restrictions, relax its requirements as to land treatment. The restrictions are, however, not general, and must be determined separately for each individual case. They further state that the dilatoriness of the authorities in administering the Act of 1876 had been the cause of this Act not improving the condition of the rivers, but that this dilatoriness had probably been excusable on account of the difficulty of securing convictions against offenders. The ardour of the local authorities had also been damped because they regarded it as useless to attempt the purification of a small reach of a river so long as those above and below continued to pollute. The three Rivers Boards, formed as a consequence of the Local Government Act, 1888, had done good work, and they recommended the formation of Rivers Boards for the various watersheds of England. It was pointed out that the Commissions of 1857, 1865, and 1868 had each recommended again and again the formation of special authorities to supervise a river from its source to its mouth and that the limits of their jurisdiction should not be dependent upon arbitrary political boundaries. Each river from its source to its mouth represents a whole, and should be treated as such. The 1868 Commission considered a Central Authority, consisting of not more than three persons, as necessary. This authority should be empowered to deal with all matters relating to river pollution and should supervise the administration of the legislation. It should have the power to inspect factories, mill dams, canals, and similar works, and, when necessary, construct purification works at the cost of those interested, whether these be towns or private individuals.

The adoption of these recommendations was specially urged in the Interim Report, although difficulties could be foreseen. Not only were the interests of those who produced the sewage often diametrically opposite, but also the opinions of experts, according as these were practical men or representatives of science. Among the latter the medical men laid special stress upon bacteriological questions. These reasons were assigned for the formation of a Central Authority, perhaps as a special department of the Local Government Board, which should be the river authority for the country. It should deal with all matters relating to rivers and their purification, follow the technical and scientific work on the subject, and, when local authorities were in default, it should be empowered to take necessary steps on its own initiative.

Trade-Refuse Difficulties.—The Second Report deals with matters outside the province of this book. The Third Report, issued in 1903, discusses the difficulties which have arisen from the nebulous state of the law dealing with the relations of manufacturers and local authorities. The Public Health Act of 1875 empowers an owner or occupier of land to connect his sewers with those of the sanitary authority. The 1876 Act provides that every sanitary authority shall give facilities for enabling manufacturers within their district to carry the liquids proceeding from their factories into the public sewers, but a couple of provisos destroy the clearness of this section of the Act. The first provides that the sanitary authority shall not be compelled to admit into their sewers any liquid which would prejudicially affect such sewers or the disposal by sale, application to land, or otherwise, of the sewage matter conveyed along such sewers, or which would, from its temperature or otherwise, be injurious in a sanitary point of view. The second sub-clause provides that no sanitary authority shall be required to admit trade refuse into its sewers, where these are only sufficient for the requirements of the district or where such admission would interfere with any order of any court of competent jurisdiction respecting the sewage of such authority. It would indeed be difficult to find a better example of legislation being rendered practically useless from the beginning by the insertion of similar clauses. If a town does not wish to admit trade refuse into its sewers it has only to declare that the sewers are not large enough. Even in the construction of new sewers, cases have occurred in which it has been decided that the authority need not make these large enough to convey the trade refuse of the district.

As a typical case an action may be referred to in which a local authority sought to obtain an injunction restraining a firm of tanners from discharging the effluent from their tannery into the sewers. The question before the Court ultimately resolved itself into whether the trade refuse destroyed the micro-organisms in the sewage and thus so changed the sewage as to interfere with its purification by biological methods. The evidence of the numerous experts was contradictory, and the Court adopted the view of the manufacturer that the tannery refuse did not interfere with the treatment of the sewage, the bad effluents from the sewage works being due to mismanagement. The costs in this action were £7000. The recognised costs fell upon the local authority, but the tanners were mulcted in over £1000.

The Commissioners state that the uncertain position of the law, as shown in this and other actions, considerably hampers the progress of river purification. The manufacturers repeatedly state that they are in communication with the local authority with a view to discharging their effluents into the sewers. The local authority then frequently drift along for years and finally state that they are not bound to accept the trade refuse. Manufacturers are thus placed in such difficulties that they would welcome a decision, one way or the other, provided that they all received uniform treatment. The Commission recognise that the view of the manufacturers is a fair one, but admit that by accepting trade refuse indiscriminately local authorities may place themselves in difficulties.

For example: (1) The trade effluents might be turned into the sewers at irregular intervals, so that the sewage as it arrives at the sewage works would vary considerably in composition and volume throughout the day; (2) the trade effluents might contain large quantities of solids in suspension which would tend to choke the sewers and the purification plant; and (3) the trade effluents might be very acid or very alkaline, or otherwise chemically injurious. Such difficulties could, however, be overcome, and the purification of a mixture of trade refuse with ordinary sewage is generally less difficult and less costly than their separate purification. An alteration of the law is therefore recommended, making it the duty of the local authority to provide such sewers as are necessary to carry trade effluents as well as domestic sewage and giving the manufacturer the right, subject to certain safeguards, to discharge his refuse into the sewers. These safeguards, relating chiefly to the preliminary treatment of the trade refuse before its discharge into the sewers, should be subject to confirmation by the proposed Central Authority. This authority should also be entrusted with the settling of differences between the local authority and the manufacturer. The local authority should also be expressly exempted from any liability for the infringement of riparian rights by the discharge into a sewer of water obtained by the manufacturer from a stream. The Commissioners are of opinion that the manufacturers should contribute towards the cost of sewage disposal and purification according to the preliminary treatment adopted. They also think it desirable that power should be conferred on the local authority to undertake the disposal of sludge resulting from preliminary treatment at the expense of the manufacturer, but they do not think that the manufacturer should be entitled to compel such removal. Special emphasis is laid in this Third Report upon the necessity for a Central Rivers Authority. Appeals to the Courts occupy much time, and are very expensive as well as often very unsatisfactory through want of expert evidence. They recommend that the Central Authority should have the following permanent chief officers: an administrative head, a bacteriologist, a chemist, and an engineer. The officers of the Central Authority should be clothed with the necessary powers to conduct inquiries, to call witnesses, to enter premises to take samples of the trade effluent, and generally to do such acts as are necessary for the proper performance of their duties. An increase in the number of Rivers Boards is recommended, as these generally have the sympathy of local authorities as well as manufacturers, and could thus form a court of first instance in differences between the parties, the Central Authority remaining as a court of appeal. Although the Rivers Pollution Prevention Act has been on the Statute Book for over a quarter of a century, the pollution of rivers in many parts of England still goes on unchecked, so that the protection of the rivers is a matter of such grave concern as to demand immediate attention.

Pollution of Tidal-water and Shell-fish.—A Fourth Report, issued in

1904, deals with the pollution of tidal waters. The question of the discharge of sewage into tidal waters came into prominence on account of serious outbreaks of enteric fever which were attributed to the eating of shell-fish, especially oysters. The capital invested in the English oyster industry amounts to six or eight million pounds sterling, and a good deal of harm has been inflicted on this industry by the alarming reports of shell-fish poisoning which have been circulated from time to time. In the interests of this industry, as well as of the health of shell-fish consumers, safeguards should be adopted to secure the purification of sewage, and again the necessity of a supervising Central Authority is apparent.

The above. sketch of the work and recommendations of the Royal Commission shows that these are of such fundamental importance that general legislation on the subject is now expected.

In England, then, during the last few decades, the conviction has been gaining ground that legislation alone will not achieve the required results in the purification of rivers, but that much more may be expected from the formation of a special authority consisting of experts in the various branches of the subject and occupying such a position as to command the sympathy of all parties. Such an authority should be free from bureaucratic influence, able to follow the technical and scientific advances made in the subject, and free to make its decisions, after judging each individual case on its merits.

The above description of the development of the subject might perhaps be considered rather too long, but for the fact that there is always a tendency to follow long and laborious paths, such as we have seen has been the case in England during the last fifty years. The conclusions which have been finally drawn, and the recommendations of the more recent Commissions, with which all parties seem to be in sympathy, are however applicable to all countries.

German Legislation.—In Germany exactly similar views are now being expressed, but there the subject is much more difficult to deal with than in Great Britain. In Great Britain, Scottish law is somewhat different from that of England, but, with the exception of that of the Tweed, there are no watersheds which are situated partly in one country and partly in the other; thus we do not have one and the same river coming within the jurisdiction of two central authorities.

It will have been seen that England has had to overcome considerable difficulties in attempting to purify the rivers; and if Germany had not been favoured with very large rivers, which have been able to delay the period of gross pollution which has been reached in England, it would have had to meet almost insuperable difficulties. For, almost without exception, the German rivers flow through several States, and each State has its own legislation on the subject. Attempts have been repeatedly made to obtain Imperial legislation, but the Constitution of the Empire renders this impossible. Only a few of the Imperial Laws (§ 366 of the Criminal Code and § 906 of the Civil Code) are applicable to questions of river pollution. The Introductory Act of the Civil Code expressly places water legislation in the hands of the separate States.

Questions relating to trade refuse are more easily dealt with in Germany than in Great Britain, owing to the existence of a well-formulated set of Trade Regulations. These stipulate that the authorities shall consider the possibility of river pollution before granting a concession for the establishment of any new works requiring such concession. Works already existing may be similarly dealt with as soon as any alterations to the premises are intended, and the police have power to deal with those works which do not require a concession for their establishment.

The Constitution of the Empire, however, places the supervision and legislation concerning measures to be adopted by the Medical and Veterinary Police Authorities in the hands of the Imperial Government, and hence § 35 of the Epidemic Diseases Act of June 30, 1900, stipulates that methods for the disposal of waste shall be supervised by the State, and that it is the duty of local authorities to remove nuisances and to adopt preventive measures against infectious diseases. If it is necessary that certain regulations should apply to several States, the Imperial Chancellor has to see that the State authorities adopt uniform measures, or, in urgent cases, he may issue instructions to the separate State authorities (§ 41). Provision is made by § 43 of this Act for the formation of an Imperial Council of Health, the work of which, as far as river pollution is concerned, is restricted, by a resolution of the Federal Council passed in April 1901, to those waters which flow by several of the Federal States.

In cases into which no question of danger to health enters, and to which, therefore, the Epidemic Diseases Act is not applicable, the present position of the law regarding water pollution in Germany is laid down in three decisions of the Imperial Law Court. At the request of J. König, the effect of these decisions has been summarised by H. Nottarp, of Münster, as follows: "The decision of April 19, 1882, is to the effect that any riparian owner on a private stream is entitled to prohibit the admission to any higher reach of the stream of any liquid except such as shall naturally flow into the stream. The decisions of June 2, 1886, and September 18, 1886, limit the above by deciding that a riparian owner on a private stream must suffer the admission to the stream of any liquid, whether it simply increases the volume of the stream water or is mixed with polluting matter, so long as such admission does not exceed the bounds of regularity and custom, even if the use of the water of the stream for any purpose is thereby interfered with. Whether a particular liquid exceeds in nature or volume the bounds of custom can only be decided from case to case. It would undoubtedly do so if it caused the stream to overflow, or *caused actual* damage to those lower down on the stream, or prevented the use of water which would otherwise be suitable as a source of water supply or for watering cattle."

The various Federal States each have their own laws relating to river pollution. They are mostly very old laws and some can boast of a venerable antiquity. A few, however, have only recently been passed, based upon the Imperial Epidemic Diseases Act. For example, an Act was passed for the State of Hamburg in 1905, relating to the storage and disposal of waste waters, fæcal, and other matters. This Act, together with the police regulations, is amply sufficient to enable the authorities to prevent any danger of river pollution within the State of Hamburg. For information respecting the legislation of other States, the literature mentioned in the Bibliography must be consulted.

Prussian Legislation. — The views lately adopted by the Prussian authorities are, however, of general interest. In 1894 a Prussian Water Bill was brought forward, but was shelved because it was realised that without the co-operation of other States a Prussian Act would be of little use. The conviction that Prussia as the largest of the Federal States should set an example to the others was the cause of an Order being issued in 1901 by the Prussian Government to the Presidents of the various districts. In this Order it was pointed out that differences in local and economic conditions between various provinces, and even within one and the same province, made general legislation impossible, but that the existing legislation, possibly along with a revision of the police regulations, should be sufficient for present purposes. The methods of procedure of the police authorities premise a knowledge of the condition of all streams and of the actual facts relating to the disposal of waste waters; hence it would be advisable to instruct executive officers to report all cases of pollution coming to their knowledge. Further, inspections should be made every two or three years of all streams which are at all polluted or in which pollution is to be feared. The following points should be specially borne in mind: (1) The prevention of the spread of infectious diseases; (2) the prevention of the pollution of such water as is used for drinking and other purposes; (3) protection of the public against nuisance; and (4) protection of fish-life. The possibility of danger to health has lately been recognised by the higher courts in cases where this danger was somewhat remote (*e.g.*, in some cases of bad smells), but this possibility should not be too much insisted upon, so as to damage other more important interests. Fishery interests would have, in certain cases, to be placed after those of agriculture or industry, but hard and fast rules could not be laid down, and it must be left to the local authorities to proceed as they think fit after taking into account the local and economic conditions and all the varied and opposing interests. Practical experience and the present position of science are the best guides in formulating requirements; but, on the one hand, as regards private streams, the above mentioned decisions of the Imperial Law Court must be borne in mind; and, on the other hand, as regards public streams, the principle laid down by the higher courts that no one may carry out any undertaking which exceeds the limits of general custom, except with the permission of the authorities. The police are also authorised to take action in cases of pollution when these contravene certain bye-laws or interfere with the interests of the public. The difficulties arising from the use of the term "general custom" in regard to private rivers do not occur in connection with public streams, for these cannot be the subject of private actions, as they are neither the property of the adjoining landowners nor of the exchequer. According to a principle laid down in the higher courts, action may, however, be taken against a pollution of public waters, which has not received a concession from the authorities, if such pollution exceeds the limits of general custom, even in cases where interference with the interests of the public cannot be asserted. The Order goes on to state that streams, the chief purpose of which is for drainage, especially of villages or factories, or which have factories and other buildings along the banks for considerable distances, must be treated differently to those which are used for agricultural purposes or for fisheries. If, however, the water of the stream is necessary for drinking or other domestic purposes, further measures must be taken against pollution. The actual state of things must be considered, and streams which are pure should be kept so, whilst those which are already polluted may be less strictly dealt with.

The order is accompanied with explanatory remarks in which stress is laid upon a knowledge of the scientific advances and experience gained in dealing with questions of river pollution. In dealing with pollution we have, on the one side, the volume and nature of the polluting liquid; and, on the other, the flow and nature of the stream into which it is to be discharged. Figures having a general application to these factors cannot be given at the present time.

At the same time a Royal Prussian Testing Institute was founded to collect all necessary scientific information upon which the action of the authorities could be based.

Imperial Council of Health (Germany).—In 1899 the Reichstag accepted a resolution for the appointment of a Commission to supervise those rivers which belong to several of the Federal States. The work of this Commission was later transferred to the Imperial Council of Health, which, as stated above, had been called into being by the Imperial Epidemic Diseases Act. A declaration by the Imperial Government in 1903, to the effect that the keeping of the rivers and other public waters free from pollution was to be regarded as one of the main efforts of public health administration, appears to be of great importance. The general tendency of the large growing towns and of the flourishing industries to get rid of their yearly increasing quantities of rubbish, filth, and sewage, by discharging them into the rivers, has imposed upon the State the duty of carefully guarding public watercourses. The far-reaching hygienic importance of *keeping* the rivers clean is faced by the fact that the towns and factories must be provided with the means of getting rid of all these matters for which the public watercourses seem to provide the natural outlet. Often, indeed, no other method is available, and then permission must be granted, but with certain safeguards which preclude the possibility of danger to health. Safeguards which would be generally applicable cannot be formulated, and hence each case must be specially dealt with according to local circumstances. Where the interests of a single State are concerned, matters are to be left to the authorities of that State; but where the interests of several States are concerned, the Imperial Council of Health may, on petition of the States concerned, act as an intermediary or even go so far as to advise the adoption of certain measures to prevent the occurrence of nuisance. Although the advisory reports of the Imperial Council of Health have no direct legal force, it may be expected that they will produce the necessary results on account of the position which the Council occupies. The provisions of article 76 of the Imperial Constitution do offer some means of enforcing the measures advised by the Council of Health, and hence it is advisable to see what results are produced by the Council before attempting Imperial legislation on the subject.

A comparison of the legal position in England with that in Germany shows that in the latter country matters are in many respects much more satisfactory, although the English Government has been more actively concerned for a longer period with questions of river pollution and also in spite of the fact that the condition of the English rivers has been for decades much worse than that of the German rivers is now or is likely to be for some time to come. In conjunction with the description of the conditions which have arisen in the Emscher valley, it may be mentioned that in Germany there also exists the possibility of self-help on the part of those concerned, after the pattern of the English Rivers Boards.

Purification of the Emscher.—An Emscher Regulation Commission, appointed in 1899, and presided over by the late Mr Zweigert, Mayor of Essen, prepared a drainage scheme for the Emscher and resolved to form a special Board. A special Act was obtained, carrying out this resolution in 1904. The total cost of this scheme will amount to nearly a million and a half pounds sterling, with a yearly expenditure of £100,000. This amount is to be raised by the constituent authorities of the Board, the local authorities in the Emscher area, and these are entitled to raise funds from the collieries, factories, railways, etc. in the district. It is scarcely to be expected that such energetic action will be taken against river pollution in other parts of the Empire as is being taken in the Emscher district, where the very existence of valuable industries has become so intimately bound up with the question of river regulation and purification.

Until now the authorities have dealt lightly, even with cases in which they were in a position to prevent serious nuisances in streams, as soon as they have recognised that preventive measures would impose a cost upon the industries in question. For example, the effluents of sugar factories are quietly allowed for several months in every year to grossly pollute numerous small streams, even after extensive investigations have been made into the purification of these effluents and all the attendant difficulties have been laid bare. Doubtless they will, however, keep an eye on the technical progress of the various methods of purification and take action against existing nuisances as soon as the times are ripe.

Recommendations similar to those made in Great Britain for the establishment of a special Imperial Rivers Authority have not been wanting in Germany, but they have been met by the fear that the various States would regard the control which such an authority would exercise as an undue interference on the part of the Imperial Authorities. The Imperial Council of Health may be regarded as a preliminary move in this direction, and its advisory reports have already borne advantageous results and given the authorities an idea of what a special Imperial Rivers Authority might do.

Questions of legislation on the subject of river purification have been dealt with more thoroughly in Great Britain and Germany than in other countries, and both countries have come to approximately the same conclusions, as will have been gathered from the preceding pages. A detailed study of the efforts made in other countries would disclose no new facts and may therefore be omitted here.

Present Position of the Sewage Question.—Undoubtedly the difficulties of sewage purification have been made an excuse for delay, not only by manufacturers, but also by many towns, in carrying out the requirements of supervising authorities. In some cases the supervising authorities have been too lenient, and it must be pleaded as their excuse that they have been patiently awaiting the perfection of methods of purification which it was hoped would yield better results at less cost to those who had the sewage to deal with. Such hopes were raised about fifteen years ago by the introduction of artificial biological methods. The intolerable nuisances to which some of the English rivers gave rise caused the authorities to put down hundreds of works in which these methods were applied before they had stood the test of time. The condition of the German rivers allowed the authorities to adopt a more expectant attitude. The experience which has been gained in England by the expenditure of enormous sums of money will be to Germany's advantage, and it is to be hoped that Germany will not find it necessary to pay as dearly for experiments which often proved fruitless and which the position of affairs in England made absolutely necessary.

The history of the development of methods of sewage treatment, which will be dealt with in the next chapter, shows that in no branch of science is it more necessary to be cautious in the adoption of new methods.

CHAPTER III.

RISE AND DEVELOPMENT OF METHODS OF SEWAGE TREATMENT.

Early Sewage Irrigation Processes.—So far as can be judged from the literature and official documents, the question of sewage purification was first raised in 1842 by the English authorities in a report by Sir E. Chadwick on the Health of the Working Classes. Mention is there made of the Craigentinny Meadows, near Edinburgh, which are said to have been first used in the eighteenth century. These were by no means irrigation areas in the modern sense of the term. The sewage of a part of Edinburgh flowed in open rubble drains on to meadow land, and it was soon observed that where the sewage reached, the grass grew abundantly. Hence, ditches were dug in all directions, in order to get the sewage on to sterile patches, that these might also bear a crop. The process is the same as the much older one adopted in the dry southern climates, where all waste water, even without manurial constituents, is valuable for irrigation purposes. The value of the observations on the Craigentinny Meadows lay, however, in the fact that they showed that even in our damp northern climate sewage could be dealt with on land for many decades without the latter losing its efficacy as a purifying agent. The irrigation meadows of Ashburton and elsewhere in Devon, which had been in use for sewage treatment from the beginning of the nineteenth century, served to demonstrate the same fact.

Later Sewage Irrigation Processes.—For another reason these observations were valuable. Up to that time, and even later, it was regarded as dangerous to health to flood land in the neighbourhood of dwellings. The General Board of Health, London, reported in 1854 that sprinkling water on land near houses was dangerous, and therefore it must be much more dangerous to spread sewage on land near the towns. It was not so dangerous to carry the sewage to a considerable distance in closed pipes and there spray it on the land, even with hose-pipes such as are used in gardens. It was thought that in this manner the evaporation was reduced to a minimum, and that the noxious matters were so rapidly absorbed by the soil that nuisance was avoided. This opinion was based upon experiments which had just been carried out on a large scale with the sewage of London, and a company undertook to carry sewage to the vegetable gardens near Fulham and there deal with it in this manner.

The Craigentinny experience, therefore, was considered as a proof that the flooding of land near towns, even with sewage, was not as dangerous to health as had been generally supposed.

The publications of succeeding years clearly show that the question of irrigated sewage being dangerous to health soon assumed secondary importance, and that the chief interest centred around the question of the utilisation of sewage. This direction of affairs, besides being due to the good results produced at Edinburgh, at Ashburton, and other places in Devon, at Tavistock, and at Harrow, was also due to the fact that Justus Liebig took up the question of town sewerage and declared that all those countries which emptied the sewage of their towns into the rivers, thus wasting valuable manure, would in time become impoverished. The value of sewage for manurial purposes was estimated at that time to be equivalent to eight shillings or even more per head of population per annum.

A real enthusiasm for sewage irrigation was thus developed. Every one of the numerous official reports published during the succeeding decades was unanimous in recommending towns to adopt this method of sewage treatment. An Act of 1858 gave facilities for towns to carry their sewage beyond their boundaries in order to get it on to the land. In 1862 a Committee of the House of Commons was appointed to deal with the question of utilising town sewage so as to reduce the rates and at the same time benefit agricultural interests. Experiments were carried out at Rugby by a Royal Commission to ascertain the true manurial value of sewage and the best method of distributing it on land. The Committee came to the important conclusion that the manurial value of sewage was very variable, depending upon the dilution of the sewage and the cost involved in getting the sewage on to suitable land, but they believed that a financial profit was possible in all cases where the local circumstances were not specially unfavourable. A second Committee of the House of Commons, appointed in 1864, even reported that it would be possible and advantageous to treat the whole of the London sewage on land, and that this treatment would result in a reduction of the rates.

A Royal Commission, appointed in 1857 to inquire into the possibility of utilising town sewage, reported, after eight years' investigation, that the proper method of sewage disposal was by land treatment, and that only by the adoption of this method could the pollution of rivers be prevented; that the financial results of land treatment varied with local circumstances, but yielded a profit in some cases. In 1866 and 1867 Sewage Utilisation Acts were passed, enabling local authorities to acquire land and other properties for the purposes of sewage treatment outside their own districts *or to use* land already in their possession for that purpose. In answer to an advertisement, an offer was made to carry the sewage of London forty or fifty miles to the sea-coast, in order to render the sea-coast arable. An Act was passed in 1865 authorising this undertaking, and limiting the period for the completion of the work to four years, but the work was never carried out.

Chemical Treatment of Sewage.—The Commissions appointed by the Government had all recommended land treatment of sewage, but at an early date private individuals had urged the advantages of chemical treatment. Government experts had repeatedly condemned the various chemical methods as insufficient, and in this connection a report by Austin, the Chief Inspector of the General Board of Health, dated 1857, is of special importance. In this report Austin recommends the preparation of a compost from the solid matters separated from sewage by the use of precipitants, of which he mentions lime either alone or used in conjunction with sulphate of alumina, sulphate of iron, burnt magnesia, animal charcoal, etc. He regarded the action of chemical precipitants as simply an aid to the separation of suspended matter from the sewage, and was of opinion that these suspended matters should be removed from sewage before its application to land. In this way he believed that all danger to health accompanying land treatment would be avoided.

A report of 1864 states that neither mechanical nor chemical methods can render sewage non-putrescible. These methods of treatment may yield a perfectly clear effluent, which is nevertheless capable of causing serious nuisance, and this can only be avoided by land treatment.

It will be seen from the above that, almost as soon as the sewage question arose, the Government experts adopted the standpoint which has been maintained practically unchanged to the present day. These views were not shared by the local authorities, many of whom were misled by the active propagandism of chemical methods of sewage treatment and utilisation. As soon as the inefficacy of one particular chemical treatment was realised, any new method which happened to be to the fore at the time was adopted. Thus it comes about that almost every large town in England can boast of having put to a practical test a whole series of chemical methods for sewage purification and utilisation.

Frankland's Views.—Power of observation and common sense early taught the experts of the English Government to assign a proper value to the very numerous methods of sewage treatment. Sir Edward Frankland, as a member of the Royal Commission of 1868, which issued its third and most important report in 1871, was the first to submit questions relating to sewage treatment to scientific investigation. It would hardly be correct to say that before his time no scientific work had been done on the subject, for the literature dealing with chemical methods of purification discloses much valuable work, but it is undoubtedly a fact that Frankland's conclusions, based as they were on excellent experiments, have formed the foundation for all further progress relating to sewage purification up to the present time. This fact has at times been lost sight of, but it appears to be now generally recognised.

In its Second Report, Frankland's Commission dealt with the so-called A B C process, a process of purifying and utilising sewage which was very much boomed about 1870. Frankland showed that the value of the solids recoverable from sewage by this process was almost exactly one shilling per head of population per annum, and that the actual value was less than would be obtained by using the fæcal matter alone as a manure. The Commission did not succeed, however, in obtaining from the A B C process a single sample of effluent which was non-putrescible. It is further stated that the possibilities of chemistry are unlimited, and that substances may be discovered which will precipitate the putrescible matter from sewage in an insoluble form; but that such hopes were, at that date, apparently far from realisation. The Commission adopted the view that land treatment was the best and most natural method of sewage purification, but it recognised more fully than any of its predecessors had done the difficulties attendant upon the acquirement of sufficient land for irrigation purposes. Frankland therefore conducted experiments with a view to increasing the volume of sewage which could be treated on a definite area of land. Attempts had already been made to purify sewage by means of artificial sand filters, but such filters choked up even when constructed of coarse material, such as coke. Frankland showed, however, that they did not choke if the sewage was applied in comparatively small doses and each dose allowed to trickle away before the application of the next. The best results were produced by applying the sewage every third or fourth day, and not by using the filters after the manner of waterworks filters. He named this new method "intermittent filtration." The Royal Commission of 1898 has termed it "land filtration."

Frankland's recommendations found little sympathy in England. As late as 1877 it was reported that thirty-eight towns had made unsuccessful attempts to purify sewage by means of filters. The examples cited show, however, that although attempts had been made, Frankland's recommendations had not been properly followed. It was thought, however, that the attempts had been sufficient to show the futility of artificial sewage filtration. The only example of the proper application of Frankland's method in England is furnished by Bailey Denton, who recommended its adoption by the town of Merthyr Tydvil in 1871 as a makeshift. He obtained good results, and succeeded in purifying ten or twelve times as much sewage as would have been possible by irrigation.

Bacterial Method of Sewage Purification.—Frankland's intermittent filtration was made the subject of extensive studies in the United States, and has formed the starting-point of the artificial biological processes which are receiving so much attention at the present time. In 1886 an Act for the prevention of river pollution was passed for Massachusetts. The State Board of Health was entrusted with the control of the rivers, and means were placed at its disposal for the erection of an experiment station. The Board was the means of the village of Medfield adopting intermittent filtration in 1886, and since that time many districts have followed the example of Medfield. The results which were achieved will be dealt with later. Of much more general importance, however, are the experiments which have been carried out at the experiment station erected at Lawrence. By selecting the most suitable soil, attempts were made to increase the efficiency of the method, and, finally, such coarse material was used that the sewage passed straight through without spreading over the filter. Automatic devices had to be adopted to distribute the sewage. The London authorities became aware of these experiments and had them repeated. In 1892 Santo Crimp prepared experimental filters of similar coarse material at Barking, but instead of adopting an automatic device for distributing the sewage, he allowed the sewage to remain in contact with the filter material. The results produced were so satisfactory that a one-acre filter was constructed of coke, and in this, London sewage was treated after its previous treatment with lime and copperas. Dibdin, who was then chemist to the London County Council, has fully reported upon the results of these experiments. The method was not called "intermittent filtration," but "biological method," and the name was changed later to "bacterial purification." The filters were not termed intermittent filters, but bacteria beds.

In 1896 Dibdin recommended the adoption of this method at Sutton, a small town near London, for the treatment of crude sewage without any previous chemical precipitation. During the first years the results were very satisfactory, and the Sutton experiments aroused the interest of all concerned with sewage purification. In numerous English towns experimental works were constructed to test the efficacy of the so-called "bacterial" methods. The above details were not strictly adhered to in the mode of operation; in fact, there was almost every possible variation, as we shall see later. It is not generally known that simultaneously and independent of Dibdin, J. Corbett, the Borough Surveyor of Salford, worked out a biological method of purification. His method was likewise based on the Massachusetts experiments; but in its further development it has surpassed the London methods.

The general impression soon gained ground that the effluents from bacterial purification works, which we will henceforward term "artificial biological works," or, more shortly, "biological works," were equally as good as those obtained by land treatment, and various towns agitated for the removal of the stipulation of the Local Government Board that all sewage should undergo a final treatment on land. As we have seen, a Royal Commission was appointed in 1898 to study this question, and it has come to the following conclusion:—

"After carefully considering, however, the whole of the evidence, together with the results of our own work, we are satisfied that it is practicable to produce by artificial processes alone, either from sewage or from certain mixtures of sewage and trade refuse, effluents which will not putrefy, which would be classed as good according to ordinary chemical standards, and which might be discharged into a stream without fear of creating a nuisance."

German Methods of Sewage Treatment.—Germany can boast of the oldest known example of the treatment of sewage. Since 1559 the town of Bunzlau has treated its sewage by means of land irrigation, but this seems to be a single case. All experiments in Germany, until within the last decade, have been framed upon English experiments. About thirty-five years ago, when Danzig and Berlin were sewered, they adopted land irrigation. About twenty years ago, Frankfort-on-the-Maine and Wiesbaden adopted chemical precipitation at the time when these processes were in vogue in England; and since that time some towns have adopted one method and some the other. The only new and original method which has come into use is Degener's coal dust method, which will be described later.

In 1877 the Prussian authorities laid down the principle that the discharge of unpurified sewage into the streams was in all cases to be prohibited. In many cases the degree of purification which was required could not possibly be attained, and such impossible requirements have stood in the way of sanitary progress. It was only when von Pettenkofer agitated for the adoption of reasonable requirements that the authorities began to consider what was possible, and from that time sewage purification in Germany took a turn which was characteristic and different to the development of matters in England. Since chemical precipitation methods had availed little, and given rise to nuisances of all kinds, Germany turned to the perfecting of simple mechanical screening and sedimentation methods. Sedimentation was first introduced at Marburg, and, later, at many other places, including Cassel. The authorities have further relaxed their requirements, and have gone so far as to allow, in certain cases, the adoption of screening alone to remove the coarser suspended matters.

In other countries little has been done which has left a sufficient impression on methods of sewage treatment to require mention in this short historical survey, except, perhaps, the beginnings of the septic system which were made in France, and which will be dealt with in a later chapter.

CHAPTER IV.

EARLIER VIEWS ON METHODS OF SEWAGE TREATMENT: THEIR OBJECT AND UTILITY.

Early Views on Sewage Treatment.—After the problem of sewage disposal appeared to have been solved by the introduction of sewers and the water-carriage system, the question devolved into one of river pollution and how to prevent it by treating the sewage. The English authorities soon had occasion to deal with this question; and the General Board of Health, as early as 1854, recognised the futility of attempting to "disinfect" sewage by means of chemicals such as carbolic acid. The term "disinfection" had at that time a very different meaning from that assigned to it at the present day, and simply implied a prevention of putrefaction of the sewage with the attendant odours. The process was also termed "deodorisation," and was performed with chloride of iron and lime as well as with carbolic acid. In 1864 an English Commission reported that deodorisation could not be regarded as a method of purification for sewage; that by means of chemical precipitation or filtration a sufficient degree of purification could not be attained, and that, although the effluent might appear quite clear and pure, it was still putrescible and liable to cause nuisance. Finally, it was stated that irrigation was the only method of purification.

It will thus be seen that the conclusions arrived at at that date, without the aid of our modern chemical and bacteriological methods, were practically the same as those which have again been reached after the application of modern science to the problem.

Precipitation *versus* **Irrigation.**—In selecting a method of sewage treatment at that time, the possibility of utilising the manurial value of the sewage was regarded as more important than the purification. Revenues were expected from this source, and hence it was necessary that the experts of the Government should express their opinions on the subject. The subject has only been dealt with scientifically since the appointment of the English Commission of 1868, which reported in 1870 that chemical precipitation only removed the suspended organic matters and left the dissolved organic matters in the sewage, and that these latter represented the major portion of the manurial value. This expression of opinion was called forth by the large number of methods of chemical treatment which local authorities were then being urged to adopt, and Frankland's Commission concluded that only by means of intermittent filtration or irrigation could the dissolved organic matters be removed from sewage. The purifying action of the soil was said to be due to the oxidising influence of the air, and the soil itself was likened to our own lungs. In the case of irrigation, the vegetable growths also played a part in using up the organic matter.

The Commission also thought that the discharge into public water-courses ought to be prohibited of any liquid containing more than certain fixed limits of solids, organic matter or injurious metals, or of any liquid which was coloured or reacted strongly acid or alkaline. These limits are given on p. 253.

Frankland's Fixed Standard of Purity.—It is remarkable that a savant like Frankland, whose work and opinions are in every direction so eminently practical, could recommend the general adoption of fixed standards when it must be apparent that actual circumstances are so variable; that in many cases very small volumes of sewage are admitted into large rivers in which the sewage is immediately lost, and the waters of which are not used for drinking and other domestic purposes; whereas in other cases large volumes of sewage are admitted into small streams, the purity of which is of extreme importance inasmuch as their waters are required for domestic and industrial purposes. Such facts as these make it impossible to adopt fixed standards with regard to sewage disposal and purification, and serve to emphasise the necessity of judging each individual case on its merits. The standards which were adopted by the Vienna Water Supply Commission in 1864 for drinking water, and which found favour in many places, must have had an influence on the findings of Frankland's Commission. Even for drinking water it has been shown that such standards can only serve as a general guide, and that by their rigid adoption difficulties arise. The most important point to be borne in mind, when comparing the treatment of drinking water and sewage, is that the former is to be consumed without further dilution, whereas the latter is diluted in the streams to an extent which varies from case to case. These standards were not embodied in the legal enactments, and are only mentioned here because they have exerted a considerable influence on the question of the standards which are used at the present day by certain English authorities.

The Local Government Board has been repeatedly urged to publish standards according to which the effluents from sewage works could be judged; but it has always declined to do so, stating that the requirements must vary in individual cases. The standards of the English Rivers Boards will be mentioned later.

The English Commission appointed in 1882 reported in 1884 and 1885, like the earlier Commissions, that land treatment (either irrigation or intermittent filtration) was the only method of properly purifying sewage, and that it should be adopted even in towns placed in such a favourable position as London for disposing of their sewage by discharge into large rivers. Since then the English Central Authority (the Local Government Board), as we have seen, has refused its sanction to any project laid before it, in which a sufficient area was not provided for land treatment.

Exclusion of Pathogenic Organisms.—About this time the sewage question began to grow acute for various German towns. The reports of the authorities show that they were completely under the influence of English ideas. Their requirements were even more stringent than in England, for the question of river contagion was regarded as one with that of sewage purification, and the destruction or separation of pathogenic germs from sewage was regarded as an essential part of sewage treatment. The formulation of such requirements decidedly stood in the way, and hindered hygienic progress for ten years. The weakness of these fixed rules was first made apparent by the attacks of von Pettenkofer and other hygienists, so that they were finally replaced by the Prussian Ministerial Order of 1901.

The present-day opinions as to the requirements to be fulfilled by methods of sewage purification will be discussed later (see Chapter X.).

PART II.—THE PRESENT POSITION OF SEWAGE TREATMENT.

CHAPTER V.

CHARACTERISTICS OF SEWAGE.

Appearance and Character of Sewage.—The sewage of a town sewered on the water-carriage system is a dirty grey liquid, possessing an unpleasant sweetish odour, scarcely noticeable in the open air and not repugnant, even in the sewers. It reaches the outfall in a continuous stream, upon the surface of which may be seen matches, corks, fruit skins, vegetable remains, and lumps of fæcal matter. If a fine sieve is placed in the current of the sewage, so as to retain solid matters, and these are examined, they will be found, in addition to the above mentioned, to consist of flocculent and fibrous material, rags, and small bits of paper, with perhaps a few hairs and other similar substances. A sample taken in a glass vessel looks like water which has been used for washing and cleaning purposes, and, on standing, a comparatively small amount of dirty grey slimy material settles out, without materially altering the appearance of the sample. Even after standing for twenty-four hours little further can be noticed. The liquid remains almost quite as turbid after passing through fine filter paper; but if it is passed repeatedly through the same filter paper it becomes clearer, as the pores of the filter become partly stopped by the material retained. Finally, a clear filtrate will be obtained without leaving any appreciable residue on the filter paper. If this clear liquid is allowed to stand for several days it first begins to smell slightly offensive, and then distinctly of sulphuretted hydrogen, caused by the decomposition of the putrescible matters in solution, and, finally, the odour gradually disappears. An unfiltered sample subjected to similar treatment also becomes clear after a somewhat longer period without an increase in the amount of sediment; in fact, the sediment gradually becomes smaller in amount, until only a little flocculent matter remains, and this, under the microscope, appears to consist entirely of micro-organisms. The sample is now fully putrefied; and if it has been kept in a closed vessel, it will smell of sulphuretted hydrogen, but this soon disappears on opening the vessel.

On first making observations, such as the above, one is surprised that the sewage is not dirtier and more concentrated. A comparison is involuntarily made with the contents of cesspools, and it is forgotten that the filth in the sewers is diluted with the entire water supply of the town. The undissolved solids too, such as fæcal matter and paper, are broken up by the friction with the walls of the sewers, and thus reach the outfall as a fine sludge.

It is often necessary to examine sewage, especially when it is a question of determining whether a watercourse is polluted by sewage, or when the effect of a particular method of sewage purification has to be investigated. We must then inquire whether reactions are known which are indicative of sewage. The contents of sewers, in towns where the water-carriage system has been adopted, are composed of the town's water supply mixed with fæcal matter and urine, water after being used for all domestic purposes, and all kinds of solid refuse which is not too large to be washed down the water-closets.

Separate and Combined Sewerage Systems.—What has been said is applicable to the sewage of houses, barracks, prisons, hospitals, and other similar institutions, as well as for towns which are purely residential, many suburbs of our large towns and places where no industries are carried on; but only when these places are sewered on the separate system, *i.e.* where the sewage is carried away in sewers which are separate from those receiving the rainfall. Most large towns and a good many of the smaller ones, however, collect the sewage and the rainfall in the same sewers, *i.e.* they are sewered on the combined system. In such cases the drainage from roofs and from the streets somewhat alters the appearance of the sewage, as described above. In English towns which are sewered on the separate system, it is customary to drain backyards, and roofs draining into backyards, into the sewers for dirty water, so that the possibility of refuse being washed into the rain-water sewers is precluded.

Storm Overflows.—The advantages and disadvantages of the separate system, which have been so much discussed during the last few decades, need not be enumerated here. It may, however, be pointed out that in cases where it is necessary to purify the whole of the sewage as much as possible, the separate system should be adopted, for on rainy days the volume of the sewage often increases tenfold, and even more, and it would be very expensive to have to construct sewage works to deal with this quantity. When the combined system of sewerage is adopted, storm-water overflows are invariably provided, by means of which the flow of sewage beyond a certain amount may, on rainy days, be discharged direct to the rivers. In England the requirements of the authorities stipulate that the storm-water overflows shall only come into operation when the flow of sewage is increased sixfold, and the sewage works must be constructed to deal with six times the volume of the actual sewage. Such a general requirement inflicts injustice and hardship, for it must be recognised that be mentioned that in Hamburg the water supplied by the town amounts to about 35 million gallons daily, and official investigation has shown that at least 15 million gallons are also obtained daily from private wells. This private supply has been estimated by independent investigators at 42 million gallons. It will therefore be seen that in designing a sewerage scheme the private sources of water supply should never be left out of account; and for towns already sewered, which are about to erect sewage disposal works, it is specially advisable that the volume of sewage should be accurately gauged. Purely practical as well as scientific reasons may be urged for the adoption of this comparatively inexpensive precaution.

If the volume of sewage per head of population is known for any particular town which has no manufactures, an approximately correct conclusion may be drawn as to the composition of the sewage; for the amount of refuse per head per day which finds its way into the sewers is almost the same in all places. Strictly speaking, it is the same only in those places where the mode of living is the same. During my numerous investigations I have often been led to the conclusion that the amount of refuse increases with the water consumption. I believe this is chiefly due to an increased use of soap. Wherever the water consumption reaches 35 or 45 gallons per head per day the sewage is so dilute that the small differences in the amount of refuse are of little or no practical importance.

It will be seen, therefore, that the water consumption considerably alters the concentration of the sewage. In many small towns the water consumption amounts to about 10 gallons per head per day (Göttingen, 12); in others it reaches about 20–25 (Berlin, 17·5; Cologne, 26·2; Hanover, 20·3; Dresden, 21·8, Bremen, 23·9); whilst in others it reaches almost 40 gallons (Frankfort-on-the-Maine, 38·0; Hamburg, 37·5); and, finally, some towns use much larger quantities (Freiburg in Breisgau, 73·1; Buffalo, North America, 155; Alleghany, 198). A water consumption in excess of 35 to 45 gallons per head per day can hardly be justified on hygienic grounds, except in very warm climates; and where, for economic reasons, it is desirable to reduce the consumption to within these limits, the object may be attained by the introduction of water meters and similar safeguards.

Influence of Soap on Sewage.—With regard to the nature and quantity of the refuse which converts the water supply into sewage, the following remarks are applicable, so long as the sewers contain mainly domestic sewage: As already stated, the sewage looks like water which has been used for cleaning purposes, and I believe that soap is one of the main factors which influences the qualitative and quantitative composition of the sewage. At certain times of the day kitchen refuse shows itself, and in many towns Monday is wash-day. On a small scale, as in various institutions, wash-day makes a great difference both in the quantity and soapy nature of the sewage.

Influence of Fæces and Urine on Sewage.—The opinion is often expressed that little difference is made in the character of sewage by the admission of the fæcal matters into the sewers. This opinion is based upon comparative studies made some time ago in English towns. Von Pettenkofer estimated the average yearly production of fæces at about 75 lbs. per head of population and that of urine at about 950 lbs. Other estimates agree very closely with these figures. If the above opinion is correct, we must assume therefore that, in a town with a population of 10,000, a ton of fæces and over ten tons of urine are daily discharged into the sewers without affecting the sewage. This is explained by saying that the water which is used in the water-closets dilutes the fæces to about the same strength as the household refuse, and that thus only the quantity of sewage is increased, but not its concentration. Baumeister, after making comparisons in towns which he regarded as in all respects alike, except that in some the fæces were admitted to the sewers and in others not, has adopted a different view. He states that in the former towns the amount of refuse in the sewage amounts to 186 grammes of dry material per head per day and in the latter only 100·5. These figures, which I intend to use as a basis for further calculations, were obtained from estimations of the total organic matter and the dissolved inorganic matter in the sewage. The inorganic matter in suspension was neglected, without, however, intending to deny its hygienic importance. The figures represent, therefore, the sum of the organic matters in suspension and of the total matters in solution, after these have been dried. Generally speaking, such a method of calculation would be justifiable; but Baumeister neglects one important factor, the composition of the town water, and, as he uses the Hamburg sewage to support his conclusions, it is necessary to point out this fact.

Refuse in Water Supplies.—The chemical composition of the water supplies of the various towns which Baumeister investigated is very variable. Suspended solids are generally absent, and the dissolved organic solids are generally so small as to have little bearing on this point. They amount, however, in Hamburg (average for 1900) to 9·5 parts per 100,000, in Hanover to 10·2, in Berlin to 3·2, and in Wiesbaden to 1·4. The dissolved organic solids in sewage amount on the average to 20 or 30 parts per 100,000 (Wiesbaden, 15·3; Frankfort-on-the-Maine, 22·8; Hamburg average for 1901 to 1904, 25·25; and Berlin, 28·52). It will be seen, therefore, that in Hamburg quite a third of the dissolved organic solids in the sewage are present in the water supply, and are therefore not characteristic of the sewage. In other towns this factor is not so important.

The quantity of the dissolved inorganic solids in the water supply amounts to 53·67 parts per 100,000 for Hamburg (1900), 46·8 for Hanover, 10·8 for Berlin, and 6·8 for Wiesbaden. In the sewage the quantities are 56·73 for Hamburg (average of 100 analyses), 77·5 for Berlin, and 178·0 for Wiesbaden. In other years the figures for Hamburg were different. In August 1893 the water supply of Hamburg contained 5·0 parts per 100,000 of organic and 121·25 of inorganic solids in solution, and yielded therefore 126·25 parts of refuse, as designated by Baumeister. The quantity of dissolved inorganic solids in the water supply alone was more than the entire refuse of Breslau, as calculated by Baumeister, viz., 121·25, against 108·4, and almost as large as the largest quantity of refuse found by Baumeister, viz., 189·2 parts per 100,000 for Berlin.

The use, therefore, of the dissolved inorganic solids in calculating the quantity of refuse may often give misleading results.

Refuse in Sewage.—How then shall the quantity of refuse in sewage be determined and its chemical character estimated? Undoubtedly the total quantity of suspended solids, both organic and inorganic, should be regarded as refuse. From the hygienic standpoint the organic matters are more important than the inorganic, but both have played a part in converting the water supply into sewage. Moreover, it must not be supposed that the sand and other mineral matter which deposits in the sewers are comparable with the sand to be found in river beds; for they are surrounded by organic matter, and are mixed with rags, hair, etc., so that the resulting mass is highly putrescible and not fit to be used for building or other similar purposes. In analysing the suspended matters in sewage it is customary to neglect the screenings, such as matches, fruit skins, etc. At the instigation of Rubner, Monti has made measurements of the amount of such screenings removed from Berlin sewage by a sieve having apertures about one-quarter of an inch (7 mm.) diameter. His results confirm those obtained in other towns, and show that the amount so removed is very small; in Berlin it amounted on the average to 5·5 per cent. of the total suspended solids.

The following table gives the amount of finer suspended solids found in the sewage of various English and German towns:—

Town.	Solids in Suspension (parts per 100,000).			Remarks.
	Total (dried).	Organic. (Loss on Ignition).	Inorganic. (Ash).	
Wiesbaden . . .	7·40	3·40	4·00	
Hamburg . . .	29·94	17·99	11·95	Average for 1906.
Hanover . . .	30·20	...	...	
Cologne . . .	30·30	21·46	8·84	
Essen . . .	31·86	21·34	10·52	
Freiburg . . .	35·05	19·47	15·58	
Breslau . . .	40·47	20·00	20·47	
London . . .	42·61	...	...	
Manchester . .	45·80	..	...	
Leeds . . .	60·06	...	...	
Birmingham .	68·60	...	...	
Halle . . .	101·64	40·48	61·16	
Frankfort . .	139·00	95·50	43·50	
Unna . . .	465·25	324·50	140·75	Average (own experiments).

The variations which these figures show are greater than might be expected, and they cannot be explained by variations in the water-consumption of the towns. The daily consumption of water per head of population is given for Cologne as 26·2 gallons, for Birmingham 27·5, for Manchester 29·0, for Leeds 38·5, and for Hamburg 37·5. In these five towns the question of sewage purification has been studied thoroughly for some years, and extensive analytical results have been obtained. It may, therefore, be assumed that the above figures relating to these towns represent average results, and I should be inclined to place greater reliance on them than on most of the other analytical data. Not that I assume the other results to be erroneous, for the Unna figures were obtained in Hamburg by the same method as the Hamburg figures, and are, I think, to be explained by the method and time of taking the samples.

The literature relating to the amount of suspended matters in sewage must unfortunately be regarded as very unsatisfactory, for these matters are of very great importance in questions of river pollution and sewage disposal.

Putrescibility of Screened Sewage.—If the suspended matters be completely separated from sewage, the clear product which remains is still putrescible. This is due to some extent to the urine in the sewage, but the process of sewage putrefaction is not the same as that of the putrefaction of cesspools or of urine. In the latter case the organic nitrogen is reduced to ammonium salts, and a strong odour of ammonia is produced. In the case of putrefying sewage a somewhat indefinite odour, generally termed fusty, is first produced, and then a distinct smell of sulphuretted hydrogen. The dissolved organic matters in the sewage are the cause of this putrescibility. The organic carbon and the organic nitrogen are invariably regarded as the cause of putrefaction, and the oxygen and hydrogen contained in the organic matters are rightly neglected. The organic sulphur is improperly neglected, and this neglect is not easily understood, especially when we remember that it is the reduction product of this organic sulphur, sulphuretted hydrogen, which causes putrefying sewage to be a nuisance, and that the organic nitrogen of decomposing sewage is not indicated by any particular odour, although it is in the case of putrefying concentrated urine. Based on these facts I have had experiments carried out to see if the estimation of the organic sulphur in sewages and effluents cannot be made of practical utility. After years of work the problem has found a preliminary solution in the Hamburg Putrescibility Test (p. 253).

Chlorides.—The view is often expressed that conclusions may be drawn as to the concentration of sewage from the amount of chlorides present. Urine contains about 1·1 per cent. of sodium chloride, so that the amount of sodium chloride discharged daily amounts to 12 or 16 grammes per head of population. If we take 15 as a basis for our calculations, we shall find that where the water supply is 11 gallons per head per day, the sodium chloride in the sewage should amount to 30 parts per 100,000, with a water supply of 22 gallons to 15 parts and with a water supply of 44 gallons to 7·5 parts. In certain towns such calculations may be of value; but they do not admit of a direct comparison of the concentration of the sewage of various towns. For example, in August 1893, the sodium chloride in the Hamburg water supply amounted to 82·39 parts per 100,000, which is much more than the above method of calculation would yield for the sodium chloride in the sewage, and a great mistake would be made by assuming that the sewage of Hamburg is eleven times as strong as that of Freiburg (sodium chloride equal to 7·44 parts per 100,000), and three and a half times as strong as that of Breslau (sodium chloride equal to 23·92 parts per 100,000). As an example in the other direction Wiesbaden may be cited. The sodium chloride in the water supply is 1·24, and in the sewage 61·12 parts per 100,000. From these figures the water consumption would be calculated as 11 gallons per head per day, whilst it is actually 21·2. The high figure for sodium chloride in the sewage is due to the water which finds its way into the sewers from the medicinal springs of the town.

Analyses of Water Supplies and Sewages.—The same care must be exercised in drawing conclusions from the results of all the usual determinations in sewage analysis. The following table gives the figures for some of these determinations made on the water supply of various towns:—

Analyses of Water Supplies.

(Parts per 100,000.)

Town.	Oxygen absorbed (10 minutes at boiling temperature).	Solids in Solution. (Loss on Ignition).	Free Ammonia (as NH_3).
Freiburg	0·03	2·4	0
Wiesbaden	0·04	1·4	0
Halle	0·11	2·8	Trace.
Essen	0·04	2·4	0
Hanover	0·04	10·2	0
Frankfort	0·02	2·0	0
Breslau	0·32	2·6	Trace.
Hamburg (1900)	0·43	9·5	Trace.
Berlin	0·69	3·2	Trace.

The oxygen absorbed varies between 0·02 and 0·69, the loss on ignition of the solids in solution between 1·4 and 10·2 parts per 100,000, and the free ammonia between nil and traces. The following table shows how these figures vary for sewages.

The oxygen absorbed varies from 3·29 for Frankfort to 19·80 for Halle. The latter figure is very high. Usually a figure varying between 7 and 12 is obtained in water-closet towns. Kubel's method of estimating the oxygen absorbed is by boiling for ten minutes in acid solution with a

ANALYSES OF SEWAGES. MATTER IN SOLUTION.

(Parts per 100,000.)

Town.	Oxygen absorbed.		Loss on Ignition.	Free Ammonia (as NH_3).	Albuminoid Ammonia (as NH_3).	Organic Nitrogen.	Organic Carbon.
	4 hours.	10 mins. (Kubel).					
Frankfort	...	3·29	22·80	3·15	...	1·29	...
Freiburg	...	3·65	19·47	6·67	...	...	...
Wiesbaden	...	4·00	15·30	3·70	...	0·98	...
Breslau	...	5·84	23·10	8·50	...	...	...
Berlin	...	8·34	28·52	9·95	...	...	...
Essen	...	9·41	22·90	3·42	...	1·49	...
Hamburg (1901-1904)	11·98	12·92	25·25	2·75	1·45	2·85	13·60
Halle	...	19·80	30·97	8·91	...	5 91	...
Manchester	10·41	...	...	2·27	0·52	...	...
Leeds	11·94	...	...	1·12	1·12	...	...
Birmingham	17 99	...	...	3·93	1·32	..	...

solution of potassium permanganate. The loss on ignition of the solids in solution varies in the towns named between about 15 and 30 parts per 100,000, and is thus between two and three times as large as the corresponding figure for the water supplies of Hamburg and Hanover, but about ten times as large as that for the other towns. The free ammonia in the sewage of the German towns mentioned in the table varies between about 3 and 9 parts per 100,000, a figure which is not nearly reached in the case of any of the water supplies. The free ammonia may, therefore, be said to be almost characteristic of sewage. It cannot, however, be used in order to calculate the concentration of a sewage, for it is, as a rule, a decomposition product, and will therefore be found in greater quantity in the sewage of dirty and slow-running sewers than in that of sewers which are kept clean and in which the sewage flows quickly without the fæcal matter having an opportunity of putrefying.

Calculations based on the amounts of organic nitrogen, albuminoid ammonia, and organic carbon are more free from the above objections. These substances are either absent in the water supply or present only in negligible quantities. From the amounts of these substances present in sewage, conclusions may be drawn as to its concentration, but here, again, only if the sewage is fresh; for the organic and albuminoid nitrogen is decomposed in putrefying fæcal matter with the production of free ammonia, whilst the organic carbon is partly converted into carbon dioxide.

Other analytical determinations, such as the rate at which dissolved oxygen is used up, are less important in the examination of the character and concentration of sewage than in judging of the character of effluents from purification works and investigating questions of river pollution.

Bacteria as Indication of Pollution.—With regard to the use of bacteriological methods of investigation it may be stated that the number of bacteria in sewage is generally more than one million per c.c. and often reaches as many as fifty or a hundred millions. Species of bacteria which may be regarded as characteristic of sewage are not known. The nearest approach to such a species is the *Bacillus coli communis.* This bacterium is found in the intestines and therefore in the excreta of nearly all animals. *Bacillus coli communis* derived from cold-blooded animals can be distinguished from that derived from warm-blooded animals, but those of human origin cannot as yet be distinguished from those derived from other warm-blooded animals. Hence the presence of *Bacillus coli communis* in river water is not necessarily a sign of sewage pollution, for these bacteria may have been derived from the excreta of birds. Persons suffering from typhus, cholera, diarrhœa, and other intestinal diseases, discharge the germs of these diseases with their excreta. It may also be regarded as quite possible for most other kinds of pathogenic organisms to find their way into sewage, especially if the patients are not isolated and all their discharges either destroyed or disinfected. The consequences which might arise from these facts give rise to very important questions, which will be dealt with more fully in Chapter IX.

Sewage Nuisances.—The most manifest nuisances which arise from present methods of sewage disposal are to be found in the formation of sludge deposits in the beds and on the banks of the rivers; in the turbidity and colour of the water of the streams; in the putrefactive changes which occur and give rise to bad smells, chiefly of sulphuretted hydrogen; and also in the putrefying sludge which sometimes rises to the surface of the streams and which may be seen floating about with the other suspended matters described above. Such nuisances have attained dimensions so serious in some districts that for long distances it is impossible to dwell on the banks or in the neighbourhood of the rivers. The sulphuretted hydrogen arising from the putrefactive changes is very poisonous to fish life. In streams which are excessively polluted, a characteristic sewage flora develops, and this is often the cause of some inconvenience. It was such nuisances as these which directed public attention to the question of sewage disposal and purification, a question which has grown in importance with the growth of towns and industrial operations, so that at the present day it is almost impossible to name a town which has not its own sewage problem. Even the towns which are situated on estuaries, and which, until a short time ago, felt quite safe in this direction, are now being compelled, by the oyster industries and other similar interests, to grapple with the question of sewage purification.

CHAPTER VI.

OBJECTS OF PURIFICATION WORKS.

Ratio between Volume of Sewage and that of Rivers.—In an earlier chapter it was pointed out that the problem of sewage purification has assumed various aspects from time to time. It was at first entirely neglected, then some action was taken, and, gradually, more intelligent and reasonable ideas have been developed. The most important result, which has been reached after years of discussion, is the general recognition, during the last few decades, and as far as Germany is concerned during the last ten years, that general requirements cannot be formulated for the purification of sewage. In order to demonstrate this fact, I usually draw a comparison between towns, such as Hamburg, Cologne, and Vienna, which discharge their sewage into mighty rivers and equally large towns, such as Berlin, Leipsic, Manchester, Leeds, Birmingham, etc., the sewage of which amounts in volume to a considerable fraction of that of the stream upon which these towns are situated. The former towns can discharge the whole of their filth into the rivers without leaving any noticeable traces. If the coarser suspended matters are retained, the actual point of discharge is not perceptible. Small towns of a few hundred or thousand inhabitants, which are situated on these mighty rivers, are in an even more favourable position. Between such extremes there are almost all imaginable stages, and it would be ridiculous, from both hygienic and æsthetic standpoints, if the most favourably situated of these towns were compelled to purify their sewage to the same extent as Leipsic, Manchester, etc., are forced to do, if they would not entirely mar the streams on which they are situated.

Infection of Rivers.—The question of sewage disposal is intimately bound up with that of spreading epidemics by means of polluted rivers. The danger of infection may, however, be dealt with separately from the problem of sewage purification, and such a treatment of the subject is desirable, because the problem is often only complicated by the introduction of questions of infection in cases where the possibility of infection is very remote. Each case will have to be dealt with individually according to whether or not those living lower down the stream are dependent upon the water of the stream for drinking and other domestic purposes, and the measures to be adopted in cases of epidemic disease can only be decided upon after due consideration of all the local conditions. A general requirement that all sewage shall be treated to such an extent as to destroy all pathogenic germs can certainly not be enforced at the present time.

Removal of Suspended Matters.—If we therefore sum up the position only as regards sewage purification, and leave out the question of infection, we see that the first requirement of any method is that the grosser suspended solids must be removed to such an extent that solid matters which are characteristic of sewage are not allowed to float on the surface of the streams or deposit on the banks. Such a requirement can be fulfilled by the use of gratings and screens (see p. 47). At the present time such apparatus is so designed as to retain solids of a diameter of about one-twelfth of an inch or even less, but many engineers regard it as an open question whether it is advisable to retain solids of a diameter of less than about one-eighth of an inch by apparatus of this kind.

In cases where it is necessary to adopt further measures in order to prevent the discharge of all the solid sewage matters into the streams, sedimentation (see p. 65) and chemical precipitation (see p. 97) may be resorted to. If further requirements are to be met, so that it is necessary to attack the dissolved solids and to obtain an effluent which is non-putrescible, we have at the present time only biological methods at our disposal. These are methods by which the dissolved solids are removed from sewage by processes of absorption and are then decomposed by the action of micro-organisms and finally oxidised. The oldest of these methods is irrigation (see p. 101), to which must be added Frankland's land filtration (see p. 118), which has now been practised for over thirty years. Finally, we have artificial biological methods, which have arisen out of Frankland's method and which have been in use for a little over ten years.

It is not advisable to treat the sewage by any of these three biological methods before it has undergone some sort of preliminary treatment in order to remove some of the suspended matters. The opinion is more and more gaining ground that biological methods should only be used after the suspended solids have been removed from the sewage as much as possible. Detritus tanks and screens only rarely afford sufficient preliminary treatment, and usually either sedimentation, chemical precipitation, or septic action has to be resorted to.

In addition to the above biological methods, Degener's lignite method can be applied so as to yield a non-putrescible effluent.

None of these methods of purification ensures the complete removal of pathogenic germs from the sewage, and hence, in cases where such removal is necessary, disinfection (see p. 228) must be carried out.

The above methods of treatment are more fully discussed in the three following chapters.

CHAPTER VII.

DESCRIPTION OF METHODS FOR THE REMOVAL OF SUSPENDED MATTERS.

A. Detritus Tanks.

Detritus tanks or grit chambers are almost always constructed in combination with sieves, gratings, or other screening arrangements. This is accounted for by the historical development of these contrivances. Gratings were first used as safeguards for the sewage pumps; they reduce the velocity of the sewage current, and thus cause the deposition of the heavier solids. In order to facilitate the removal of these solids by means of dredgers or other similar forms of apparatus, cavities were made in which the solids deposited more readily.

Sloping Bottoms.—The oldest forms of detritus tanks are therefore merely cavities constructed with either a rectangular or circular cross-section, as shown in the Berlin grit chambers (fig. 1). The first improvement was made on these older forms by giving the bottom of the tank an inclination towards the end at which the sewage enters. In a few cases the inclination of the bottom of the tank was to the other end (fig. 2), but

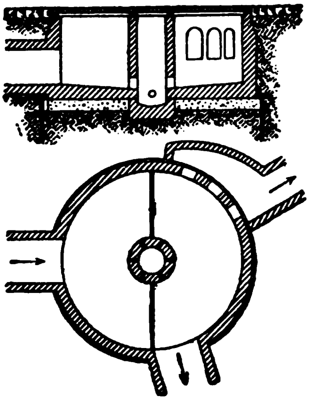


Fig. 1.—Berlin Detritus Tank.

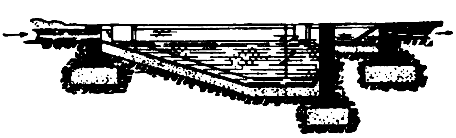


Fig. 2.—Detritus Tank adopted in England. Longitudinal Section.

such a construction can hardly be justified even for sedimentation tanks in which much lighter solids have to be arrested, and those constructed by Mairich for the town of Ohrdruf (fig. 3) are on the proper principle.

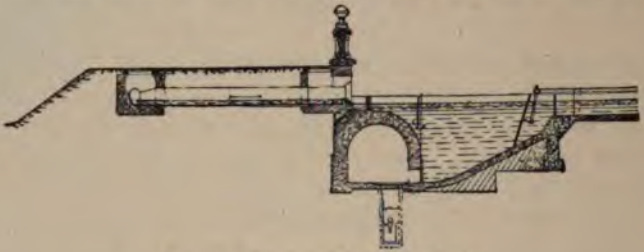


FIG. 3.—Detritus Tank (Ohrdruf).

Removal of Detritus. — Sand and other heavy material is not distributed over a large area of the bottom of the tank, but sinks, immediately on entering the tank, to the deepest point, from which it can afterwards be removed. In small works this removal is effected by hand labour, or, as in the case of the Ohrdruf tanks, by opening a valve and allowing the detritus to fall into buckets, which are then removed through the tunnel shown in cross-section in the figure. Vessels may also be placed in the tanks to catch the detritus, as shown in fig. 4, a method adopted by the General Town-Cleansing Co., Berlin.

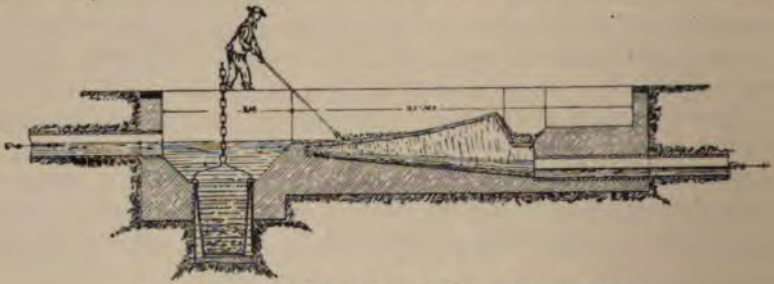


FIG. 4.—Detritus Tank (General Town-Cleansing Co.).

In Schneppendahl's apparatus perforated metal vessels are lowered into the detritus chambers by means of a crane, and raised when full of detritus (fig. 5).

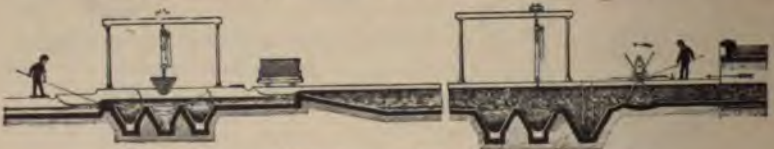


FIG. 5.—Schneppendahl's System of Sieves and Detritus Tanks.

Usually detritus tanks are separate from the other portions of the *purification* plant, but at Cologne they have been constructed by

Steuernagel as a part of the sedimentation tanks, which will be described later, at the end where the sewage enters (fig. 6). In this case the detritus is sucked out of the detritus chamber by means of an evacuated vessel.

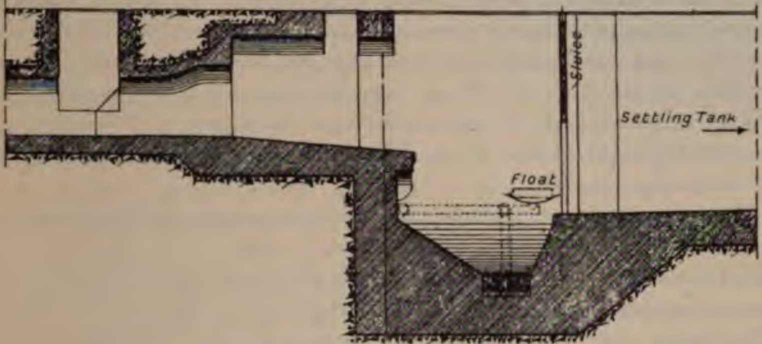


FIG. 6.—Detritus Tanks (Cologne).

Elevators and Grabs.—In many larger works the detritus is dredged out of the detritus tanks. In most large towns known to me the bottom of the tank is level or approximately level, and the dredger is moved gradually backwards and forwards, so that it commands the entire bottom of the tank. Such is the case at Hamburg. In Birmingham a grab (fig. 7) is employed, and this is attached to a travelling crane, so that the detritus may be removed from any portion of the large flat-bottomed detritus tanks.

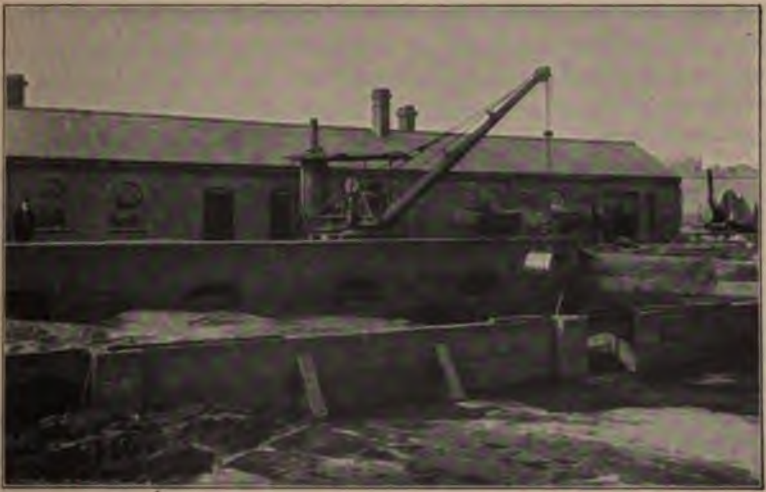


FIG. 7.—Grab Dredger used at Birmingham.

Detritus tanks are seldom omitted at sewage works. Such is, however, the case at Cassel, where the sewage enters direct into the sedimentation tanks; this precludes the possibility of removing the sludge by pumping, on account of the coarser solids which would injure the valves of the pumps, and hence a vacuum apparatus has to be employed. In Marburg also, no detritus tanks precede the screening apparatus constructed by Riensch; one of special form was constructed after the screens, but as it did not fulfil the purpose for which it was intended, it need not be described here. The works which Riensch constructed at a later date in Düsseldorf are, however, provided with very shallow detritus tanks which precede the screening apparatus.

The dimensions of detritus tanks are generally so arranged that the velocity of the sewage as it passes through them is not more than two inches per second. As the tanks are usually very short, the sewage only remains in them for a few minutes. In the experimental plant at Cologne the detritus tank is only about 3½ yards long; the Frankfort detritus chambers are about 6½ yards long, whilst in Manchester they are 9 yards long, and on wet days they have to deal with very large quantities of detritus, as Manchester is not provided with catchpits in the street gulleys. The detritus tanks at the Paris pumping station at Clichy are as much as 70 yards long.

In the Dresden experimental plant the form of construction shown in plan in fig. 34 (p. 61), is said to have yielded good results. The tank is circular, 6½ yards in diameter, and is constructed to deal with 10 million gallons of sewage daily. It was first constructed in the form of an inverted cone, but observations led to this form being abandoned in favour of one with a flatter bottom, and with a second detritus tank built inside, and concentrically with the first. The sewage first enters the outer tank, and the current divides into two, a portion passing each way round the outside of the inner tank. The two currents meet and cause the solids to deposit. The inner tank wall is broken down opposite the point where the solids deposit, and these slide down the sloping bottom into the inner tank, from which they are removed by means of a dredger.

It is an almost invariable custom to construct two detritus tanks in parallel, so that they may be cleaned out alternately. Even where the cleansing of the tanks is performed by dredgers, the flow of sewage through the tank is generally stopped during the dredging operations. Watson of Birmingham makes an exception to this rule, for the reason that he aims at washing as much putrescible matter as possible into his septic tanks.

The Wiesbaden provisional works is the only case I know of in which detritus tanks are constructed in series. The results are said not to be encouraging.

The name "sand interceptor," which is used in Germany for "detritus tank," does not properly describe the function of this piece of plant. The matters which are intercepted in the detritus tank vary very much, in both quantity and nature, with local conditions. In towns which are sewered on the combined system, the road detritus is washed into the sewers on wet days, and the quantity and nature of this material are largely dependent upon the kind of material used for paving the roads. The long lengths of macadamised roads which are connected with the Birmingham sewers yield extraordinarily large amounts of mineral detritus. This is largely intercepted in the street gulleys; but in some towns, such as Manchester, the street gulleys are not provided with catchpits, and the whole of the road detritus is washed down to the sewage works. After heavy rain the quantity of detritus may be as much as three hundred tons in a single day. In towns which are sewered on the separate system the detritus tanks have less work to perform on account of the absence of road washings.

As a rule, sandy material is one of the chief constituents of the contents of detritus tanks, but, as already stated, this material must not be regarded as pure sand. Even under the most favourable circumstances, it is mixed with fibres and organic matter which have been carried down along with the sand, and it is hence rarely suitable for building or other purposes; in disposing of it, its putrescible nature must be borne in mind.

The amount of material which detritus tanks remove from sewage, for the reasons given above, cannot be expressed generally in terms of the volume of sewage or of the population, but the data given on p. 258 have been obtained from the figures of various towns.

B. Sieves, Gratings, and Screens.

Until about twenty years ago, sieves, gratings, screens, and other similar arrangements for intercepting the suspended matters from sewage, were only used in cases where the sewage had to be pumped and for the purpose of retaining large materials and mineral matter which would interfere with the working of the pumps. In most countries, even at the present day, they are only of secondary importance. In Germany, however, during the last ten years, screening has developed into a method of primary importance, which is used in all cases where sewage is discharged into such large rivers that a suitable dilution of the sewage is attained, and where therefore the treatment is carried out rather for æsthetic than hygienic reasons, to prevent the appearance of unsightly objects either on the banks of the river or on the surface of the water. The suspended matters are also able to act as vehicles of infection. During the last few years such screening apparatus has been erected at Cologne, Düsseldorf, Göttingen, Dresden, Hamburg, and at numerous other smaller towns.

The problem of arresting all the suspended matters from sewage down to a size of one-eighth or even one twenty-fifth of an inch, without the erection of large tanks to reduce the velocity of the sewage, is not an easy one. This is due to the peculiar nature of the suspended matters; for fibrous material, pieces of paper, hair and similar materials form a felt-like covering on the screens, and make it difficult to keep the openings free.

The difficulty of the problem has taxed the ingenuity of many engineers, who have invented many mechanical forms of construction, and the development of all these various kinds of screening apparatus is indeed a very interesting study.

Bearing in mind the increasing importance of mechanical screening apparatus, which is now to be found at almost every sewage works, I have tried as far as possible to give a complete review of the various types which have been adopted.

Gratings as used to protect sewage pumps were mostly constructed of round bars of iron, placed from five-eighths to one inch apart. The material which they retained was removed with hand rakes. Occasionally a movable grating of this kind was placed before a fixed one, so that the motion of the grating broke up fæcal and similar matters and made it possible for them to be pumped.

Coarse Filters.—About the time when a large number of towns in England were experimenting upon the treatment of sewage by means of filtration, the sewage was often subjected to some kind of preliminary treatment in order to prevent the filters clogging. Generally a filter of very coarse coke or slag was employed, and this acted like a sieve in keeping back the grosser solids. In America straw matting was used for a similar purpose. The sewage was also allowed to flow over surfaces covered with rough stones; these surfaces were alternately put out of use, and the organic matters which had been retained then dried up and could be easily removed. All these primitive arrangements, however, either soon clogged up or gave rise to nuisances in the neighbourhood. The next development was to place sieves at various angles, and even horizontally (fig. 8), in the current of the sewage. They were also placed on hinges, like doors, in the sewers (fig. 9), and perforated metallic baskets were also used to catch the grosser suspended solids (fig. 10).

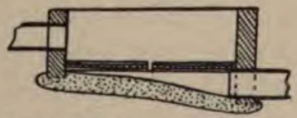


FIG. 8.—Sewage Sieve (Wayne).

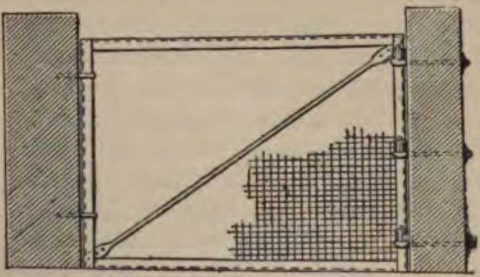


FIG. 9.—Sewage Sieve (White Plains).

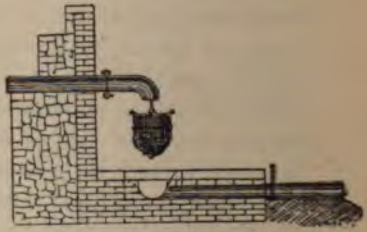


FIG. 10.—Perforated Metallic Basket (Rhode Island).

In Bonn, where there were difficulties in uniting the various sewers into a single outfall sewer, and where the authorities in 1903 stipulated for the removal of solids larger than one-fifth of an inch, man-holes have been built near the outfalls of the separate sewers, and perforated baskets are lowered into these. The sewage passes through the baskets, which are raised out of the man-holes by means of cranes for cleansing purposes.

Metzger has constructed the form of screening apparatus shown in figs. 11, 12, and 13, for the towns of Bromberg and Insterburg. The sewage enters the channels (*a*), and overflows on to the grids (*c*), which have $\frac{1}{8}$-inch apertures, and which slope very slightly upwards in the direction of the current. As soon as the lower portions of the grid become stopped up, the sewage rises, and the suspended matter is carried to the upper portions of the grid. A brush (*e*) continuously removes the solids from the grid into the channel (*f*), from which they are removed by means of a worm-conveyor into specially constructed vessels (*i*). The apparatus is constructed in duplicate, and the brushes are worked alternately. The special advantage which Metzger claims for this apparatus is that the retained solids are immediately removed from the sewage and not left to be pressed into the apertures of the grid by the current of the sewage, as is the case with vertical grids. The grid is four times as large as the cross-section of the sewer.

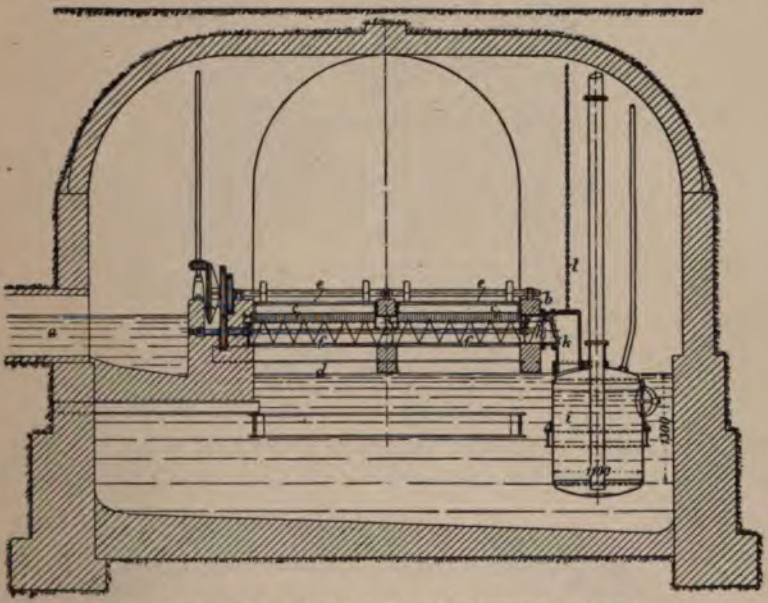


FIG. 11.—Screen with Automatic Cleansing Apparatus (Bromberg).
Longitudinal Section.

In many of the more modern forms of screening apparatus a grid is fixed vertically or nearly so in the current of the sewage, and from this the solids are removed by a movable grid provided with forks or rakes. The prongs of the forks enter the apertures of the fixed grid and carry the solids upwards. The oldest apparatus of this kind which is known to me is at the Clichy pumping station in Paris (fig. 14). In this case the grid is fixed obliquely against the current of the sewage, and, as soon as the prongs of the forks reach the upper end of the grid, they tilt vertically and the solids drop into a trough. In Manchester the same

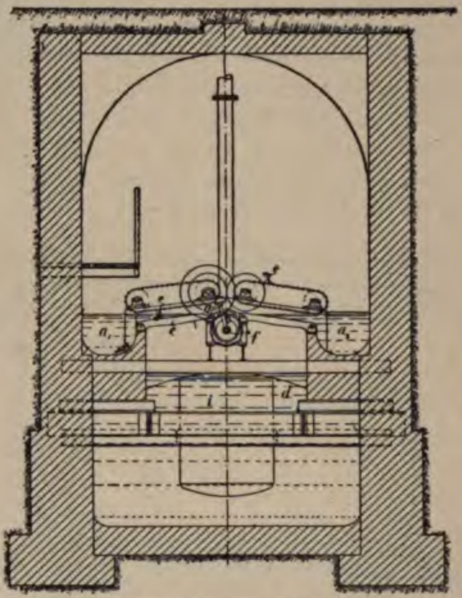


FIG. 12.—Screen with Automatic Cleansing Apparatus (Bromberg). Cross Section.

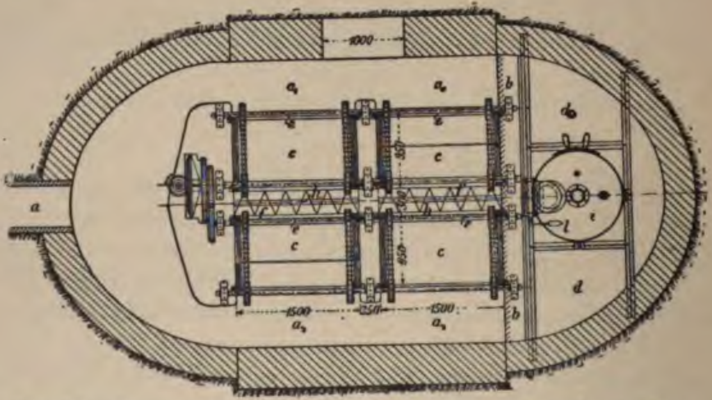


FIG. 13.—Screen with Automatic Cleansing Apparatus (Bromberg). Plan.

principle has been adopted, but the grid is placed obliquely in the same

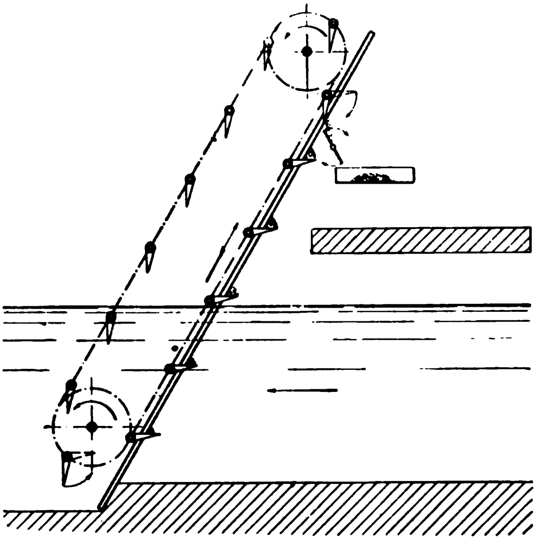


FIG. 14.—Screen with Automatic Rakes (Clichy, Paris).

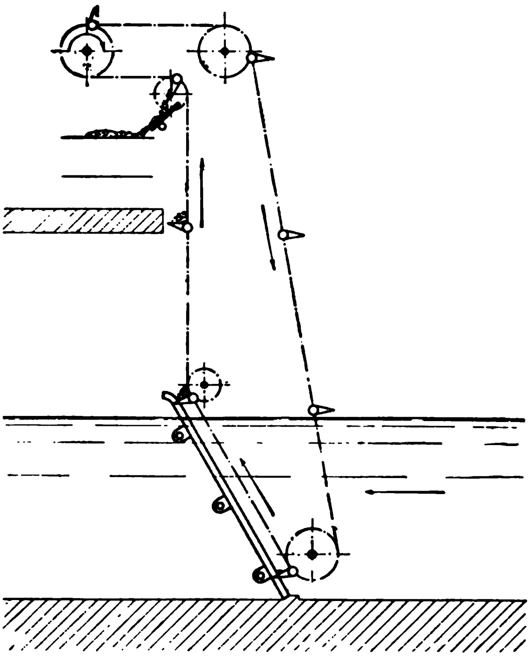


FIG. 15.—Screen with Automatic Rakes (Manchester).

direction as the current of the sewage, and therefore the travelling screen is on the approach side of the grid (fig. 15).

In the perfection of mechanical apparatus for retaining solids, most valuable service has been rendered by the engineer, Hermann Riensch, who has been incessantly engaged for over ten years in devising forms of apparatus which will retain even the finest particles and in which the objectionable labour is performed automatically instead of by hand, as formerly. His first experiments were made on trade refuse, from which he succeeded in recovering valuable materials. His experiments on sewage were carried out first at Wiesbaden, and then, on a larger scale, at Marburg. Continually introducing improvements, Riensch has devised the screening apparatus at other towns, the latest form being that at Düsseldorf. The principle adopted is an extension of that in use at Paris and Manchester. Instead, however, of reducing the velocity of the sewage current before the screening apparatus, as is usually the case, it is accelerated at Marburg, in order to carry all the suspended matters and the detritus on to the screens. Riensch's coarse and medium screens are not straight, but bent in the form of a segment of a circle (*a*, fig. 16). The apertures of the coarse screen are rather over half an inch wide, those

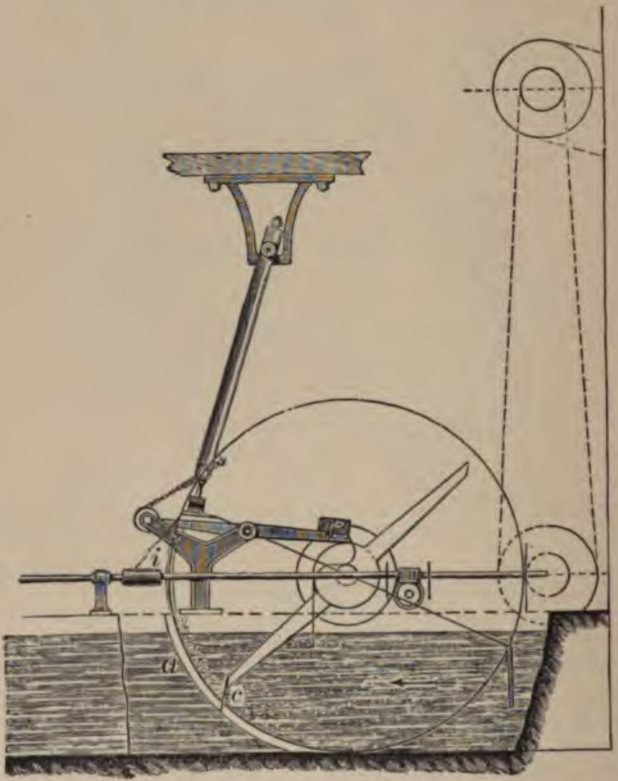


FIG. 16.—Riensch's Medium Screen. Longitudinal Section.

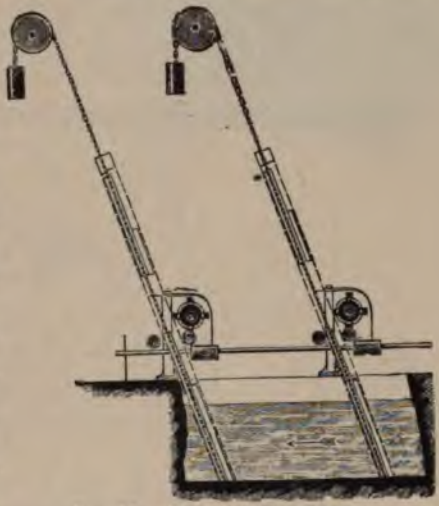


FIG. 17.—Riensch's Fine Screen.

of the medium screen about a quarter of an inch, and those of the fine screen about an eighth of an inch. In Marburg the fine screen (fig. 17) was constructed of wire fixed into a frame, and had apertures about $\frac{1}{25}$-inch wide. It was automatically raised out of the sewage as soon as it became clogged, but was not very satisfactory. The fine screens are now constructed like the medium ones, which are automatically-cleansed by means of a rotating comb (*c*, fig. 16), the steel teeth of which fit between the bars of the screen and raise the solids to a strip of metal (*i*, fig. 16). From this a brush removes them to a travelling apron (*b*, fig. 18), which conveys them into waggons.

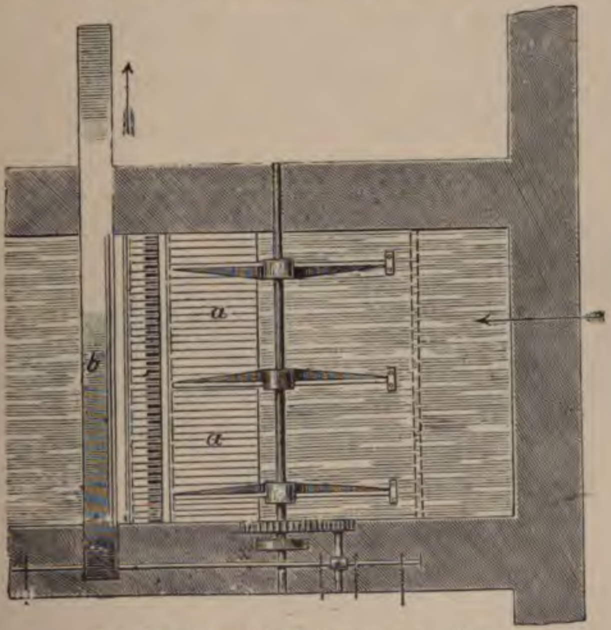


FIG. 18.—Riensch's Medium Screen. Sketch.

Movable Screens.—In 1899 Schneppendahl, the manager of the Wiesbaden Sewage Works, constructed an apparatus in which the screen was not fixed but movable, in the form of a so-called wing screen. The five or six wings of the apparatus each consists of a screen, and the bed of the sewer is so hollowed out in the form of a segment of a circle that in any position of the rotating screen the entire cross-section of the sewer is closed by one of the wings. The screen is revolved against the current of the sewage. The solids are raised out of the sewage and brushed off into troughs. We shall see later that this very practical form of apparatus, which, so far as I know, was first adopted by Schneppendahl, has been variously modified and utilised in other places. Schneppendahl believes that it is not advisable to remove solids less than $\frac{1}{5}$-inch or $\frac{2}{5}$-inch in size by means of such apparatus, and he has therefore constructed a system of grit chambers (fig. 5), provided with perforated metal vessels before the screening apparatus. Uhlfelder has adopted the rotating wing screen (fig. 19) at Frankfort-on-the-Maine. The wing screens adopted at Allenstein do not rotate in the sewage, but, for cleaning purposes, are raised by hand and the solids emptied into waggons (figs. 20 and 21).

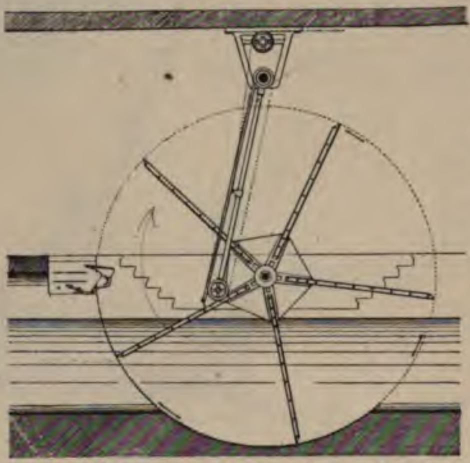


FIG. 19.—Winged Screen. Longitudinal Section.

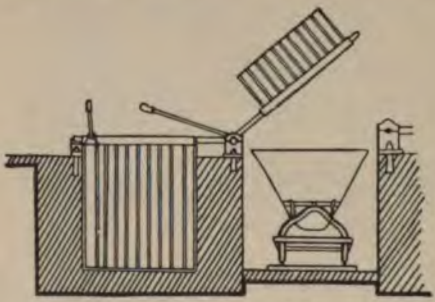


FIG. 20.—Winged Screen (Allenstein).

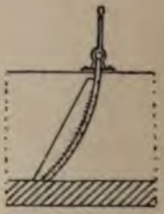


FIG. 21.—Winged Screen (Allenstein).

In the attempt to perform all objectionable labour connected with sewage treatment automatically, without the necessity of hand labour, the use of fixed screens is gradually being abandoned in favour of movable ones, from which the solids can be removed more easily after being raised out of the sewage. There are two main types of this kind of apparatus, *viz., movable sieves*, which are constructed either of perforated or woven metal, and movable gratings which are constructed of bars. The form manufactured by John Smith & Co. of Carshalton, and shown in figs. 22 and 23, has been adopted in various English towns, and, so far as I could learn, has everywhere given satisfaction. On account of its simplicity, the apparatus impressed me favourably. A sieve of woven wire (*a*) is placed over two movable cylinders (*b*), which are generally operated by means of an under-driven water-wheel (*d*) placed in the current of the sewage. The solids are swept from the sieve into a trough by a rotating brush (*c*).

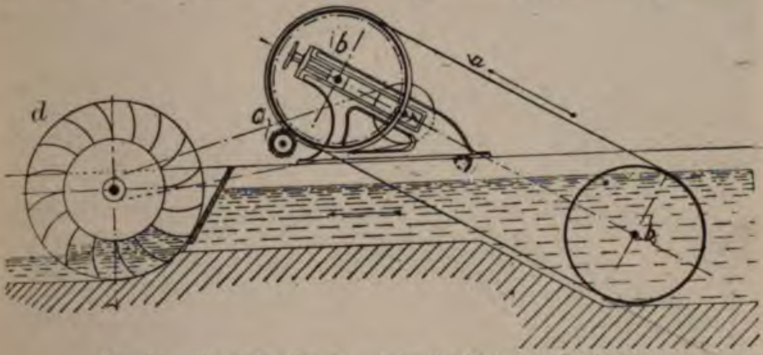


FIG. 22.—Revolving Screen. John Smith & Co., Carshalton.

A similar form of apparatus was constructed by Herzberg at Göttingen, and put into use in 1903. The wire sieve is not simply woven, but constructed more like a spring mattress, and with a $\frac{2}{5}$-inch mesh. Pieces of brass are attached to the sieve, which is of copper, at distances about a yard apart, in order to prevent the solids from sliding down. The sieve is driven by steam power at a velocity of about $2\frac{1}{2}$ yards per minute. As in Smith's apparatus, the solids are swept from the sieve by a brush which rotates in the opposite direction to the screen. The action of the brush is aided by little jets of water, supplied from underneath by a perforated tube. The solids fall into waggons from which the excess water drains back into the sewer. The drained solids are then mixed with peat dust and street sweepings, and made into a compost for agricultural purposes.

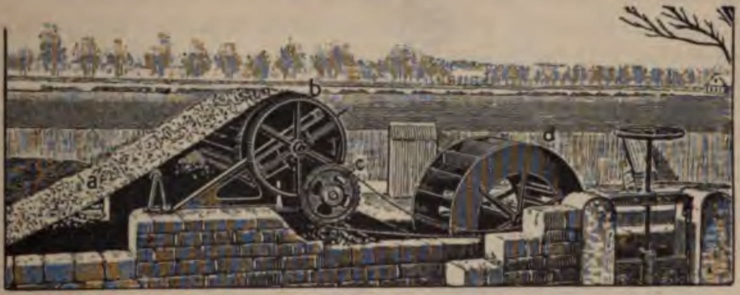


FIG. 23.—Revolving Screen. John Smith & Co., Carshalton.

Besides wire, other woven materials have been recommended for the removal of the solid matters from sewage.

For over ten years a rotating screen has been in use at Glasgow. It is constructed of flattened iron bars, placed about three-quarters of an inch apart, and provided with projecting angle irons to prevent the solids from sliding down. At Hamburg a screen of similar construction was introduced a few years ago. In appearance it resembles the rotating sieve manufactured by Smith & Co. It is not a sieve, however, but a movable grating constructed of bars (fig. 25). The separate bars are about 15 inches long, and they are placed about $\frac{3}{8}$-inch apart, so as to form sections of the screen 3 yards wide. The whole screen consists of forty-six such sections. The small bars were first constructed of caoutchouc, but this was later rejected in favour of a soft alloy. The screen is so constructed that the teeth of the rubber comb which removes the solids can pass between the separate bars. From the rubber comb the solids are scraped on to a travelling band by a strip of rubber. The velocity of the screen is from 1 inch to 1½

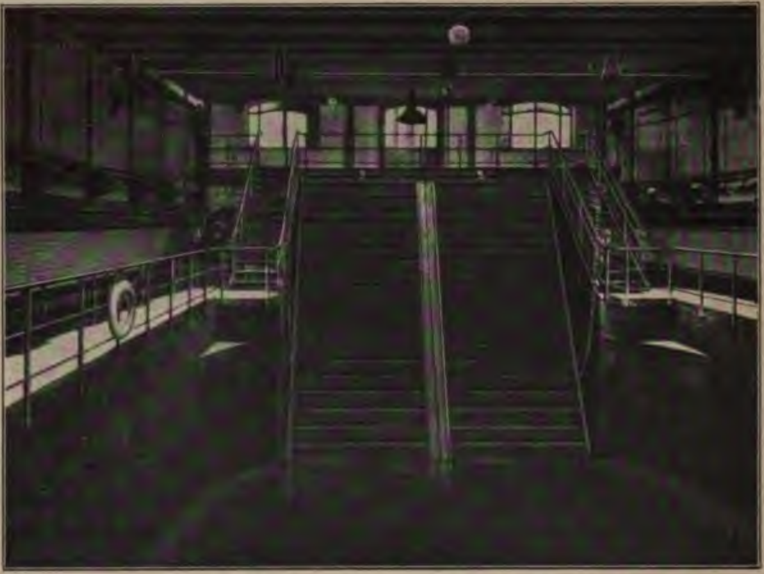


FIG. 24.—Screening Apparatus (Hamburg).

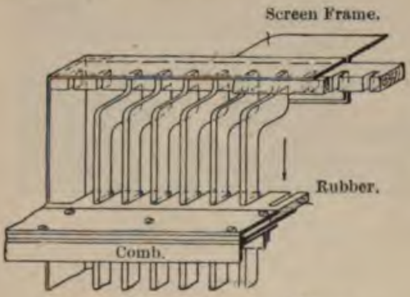


FIG. 25.—Bars of Hamburg Screen.

inches per second—a velocity which allows the apertures to be partially clogged and thus to remove finer suspended matter. The whole apparatus is built in a grit chamber, 18 yards long, 10 yards wide, and 2 yards deep, from which the sediment is dredged out and discharged on to a travelling band. The dredger is mounted on rails, which permit of its action at any point of the detritus chamber.

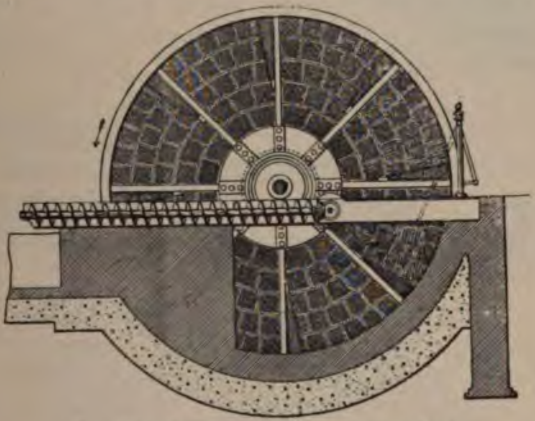


FIG. 26.—Screening Apparatus (Croydon).

The apparatus shown in figs. 26 and 27 was constructed some years ago by Latham for the town of Croydon. It consists of a woven wire sieve, stretched in the form of a disc, which is placed across the sewer and rotated by means of water power. The solids are removed from the disc by means of a worm conveyor. At first two such discs were provided at Croydon, one with a coarse and the other with a fine mesh, but the

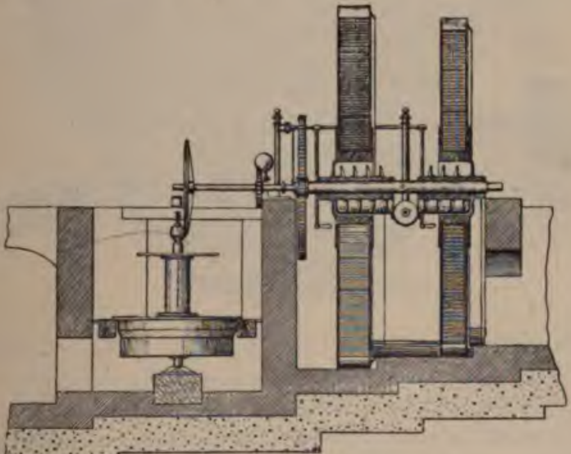


FIG. 27.—Screening Apparatus (Croydon).

coarser one was unnecessary and therefore was dispensed with. Latham's apparatus has also been adopted at Rhyl.

Friedrich's apparatus (figs. 28 and 29) also consists of a sieve in the form of a disc; it is not, however, placed vertically in the sewer, like Latham's apparatus, but horizontally. A coarse sieve and a fine sieve are provided, and these are shaken by means of springs. This shaking is intended to loosen the solids and to carry them to a discharging channel.

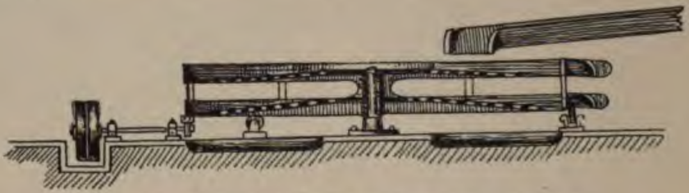


FIG. 28.—Friedrich's Screening Apparatus. Elevation.

Riensch has lately abandoned the lines which he pursued for over ten years, and has adopted forms of apparatus similar to the above. He places a disc sieve nearly horizontally in the sewage, but sufficiently inclined to permit of the retained solids being brought out of the sewage by the rotation of the sieve (fig. 30). The solids are then removed from the sieve by means of rotating brushes (fig. 31). The advantage of this form of construction over his previous forms is ascribed by Riensch to the fact that the solids are not so liable to be crushed by the apparatus and so to escape through the sieves.

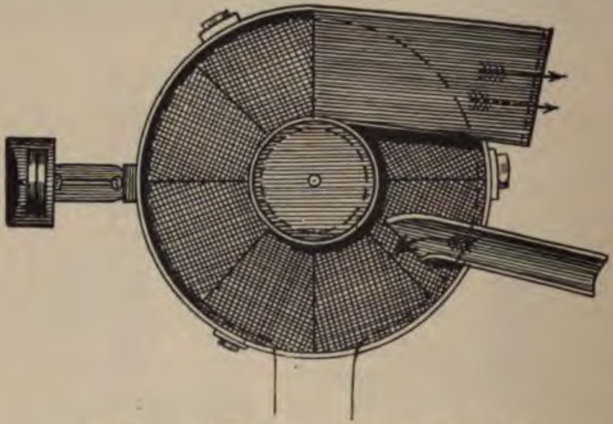


Fig. 29.—Friedrich's Screening Apparatus. Plan.

The apparatus depicted in figs. 32, 33, and 34 has been in use for several years in an experimental installation at Dresden. At this plant the sewage first passes through a detritus tank 6½ yards long (described on

p. 46), and then reaches the disc sieve, which is 5 yards in diameter and has openings $\frac{1}{12}$-inch wide. The sewage of a quarter of a million inhabitants, nearly ten million gallons daily, passes through this sieve, which retains about eight tons of solid matter daily. Sand, stones, and other detritus have been removed before the sewage reaches the sieve. The solids which are swept from the sieve fall into a pit, from which they are dredged in order to be carted away.

The Stendal sugar factory, at which Riensch made his first experiments, has adopted a form of apparatus constructed by Joerning and Sauter (fig. 35), which there gives every satisfaction. It consists of a drum sieve having openings $\frac{1}{8}$-inch wide. The solids retained on the surface of the drum form a filtering medium, which retains particles much less than $\frac{1}{8}$-inch in size. The drum is cleansed by means of a steam blower. Simplicity and durability are among the features of this apparatus.

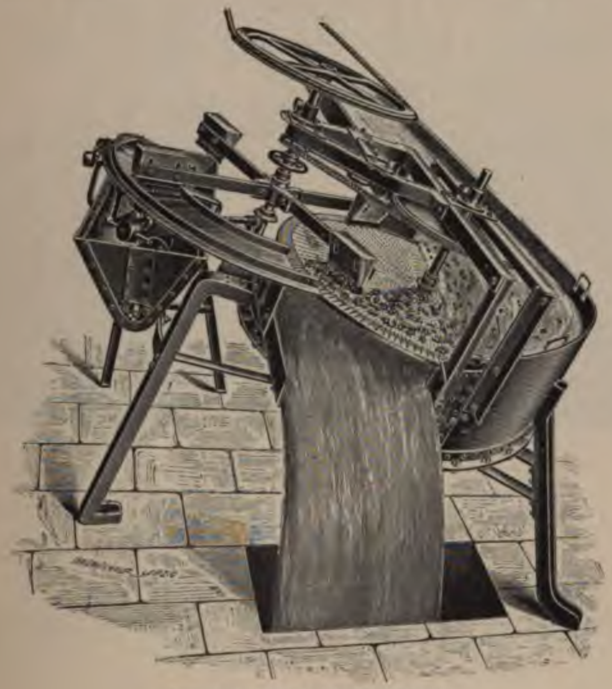


FIG. 30.—Riensch's Disc Sieve.

Finally, it should be mentioned that centrifugal force has been recommended for the removal of suspended matters from sewage.

C. Grease Extraction.

Grease in Sewage.—Although it is the custom in sewered towns to insist upon the provision of grease traps at all places where grease is likely to enter the sewers, this does not prevent considerable quantities of fat and oil from becoming mixed with the sewage. Degener examined the air-dried sediment from the sewage of various towns, and found that it contained quantities of grease varying from 4 to 18 per cent. Of this grease, 20 per cent. was neutral fat, 50 to 70 per cent. fatty acids, and

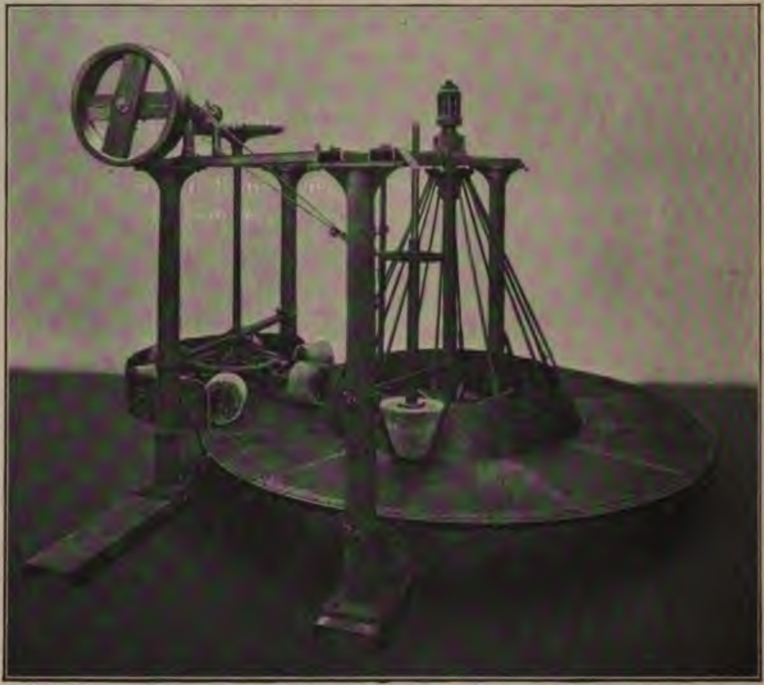


FIG. 31.—Riensch's Disc Sieve.

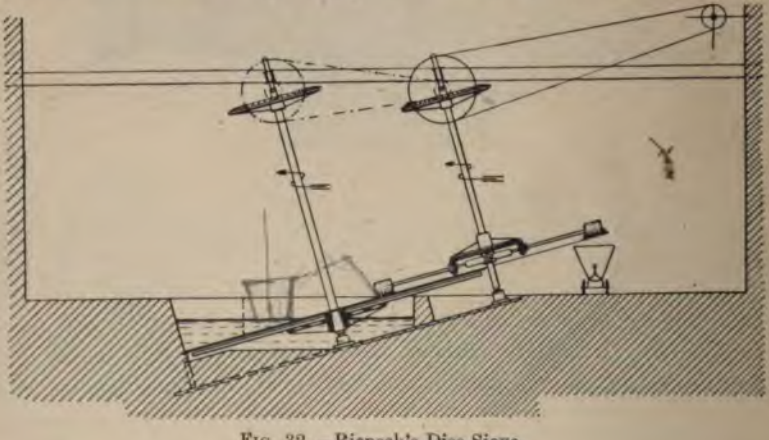


FIG. 32.—Riensch's Disc Sieve.

30 per cent. unsaponifiable wool oils. Degener considered that the composition of this grease rendered it very suitable for the manufacture of candles, soap, and olein. On his recommendation, the recovery of this grease was first carried out on a large scale at Cassel, where the sludge from the settling tanks was submitted to benzol extraction; later the

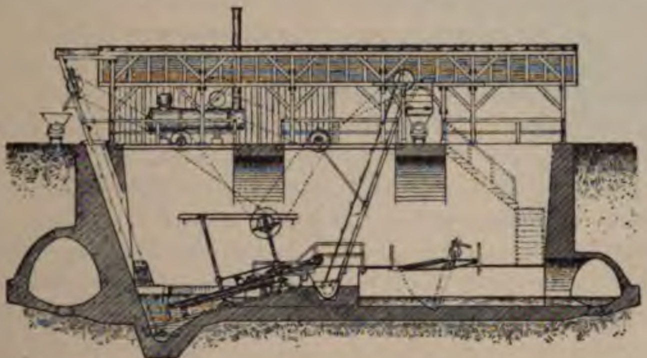


FIG. 33.—Riensch's Experimental Works (Dresden). Longitudinal Section.

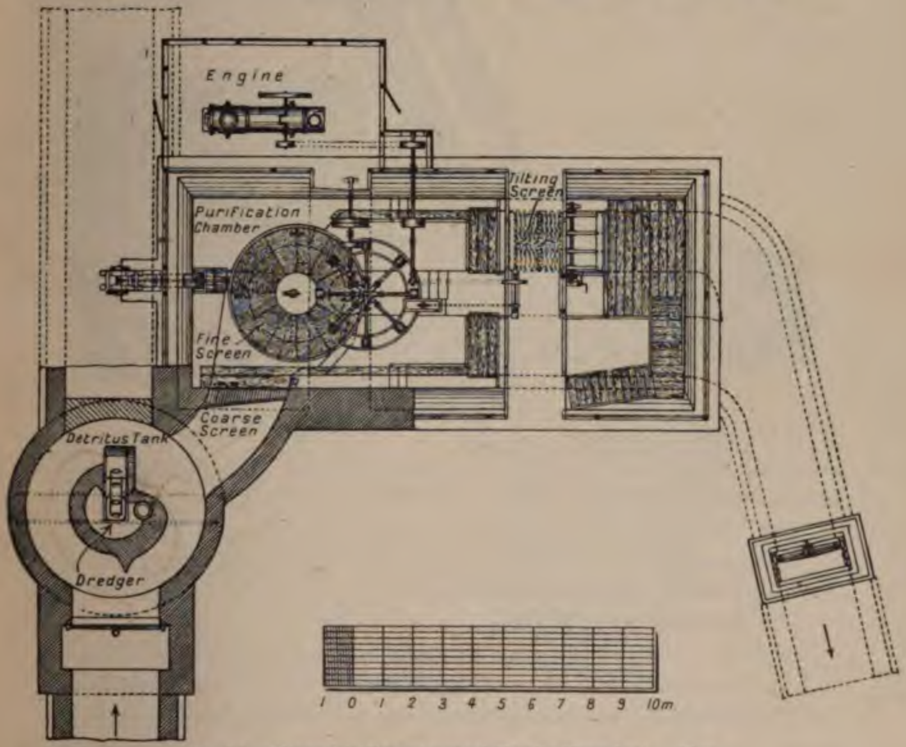


FIG. 34.—Riensch's Experimental Works (Dresden). Plan.

use of carbon bisulphide instead of benzol was recommended. For several years the reports on this process were very promising, but at length it was shown that the cost of the grease extraction was so high as to render the process unprofitable.

Grease Extraction in Woolwashing.—The woolwashing works in Yorkshire have used various methods of grease extraction for a considerable number of years. Usually the grease was only extracted from sludge, as at Cassel, and it was found advantageous to add chemicals to the liquid waste in order to carry the grease down with the sludge. Such a large quantity of sludge was produced in this manner, however, that the recovery of the grease by means of sulphuric acid, steam, and benzole, was not profitable. The sludge, after being heated to reduce its moisture to about one-fifth of its original value, was therefore centrifugalised. This process yielded three layers, viz. :—

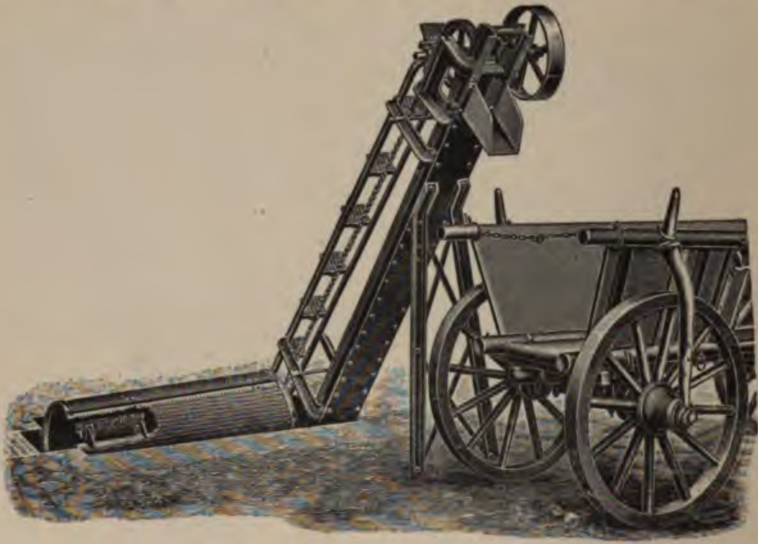


FIG. 35.—Screening Apparatus by Joerning and Sauter.

1. Sludge which was not further utilised.
2. A concentrated potash-soap solution, which was burnt for the recovery of potassium carbonate.
3. Commercial crude lanoline.

So long as the market price of crude lanoline stands at £20 and of potassium carbonate at £23 per ton, the process is said to be profitable.

It is apparent that such processes are not directly applicable to the conditions of towns where the grease in the sewage is incomparably less than in the refuse from woolwashing.

Grease Recovery.—Lately, much interest has been shown in experiments in which not the sediment from sewage, but the floating matter, has been utilised for the recovery of grease. The Frankfort Company for the Utilisation of Town Refuse has made use of the apparatus shown in fig. 36. Four cylinders are placed one within the other, the innermost one being closed in the form of a bell. The incoming sewage is distributed over this bell, and enters the interior (*a*), where the major portion of the floating matter is retained. In the next cylinder (a^1), some of the grease particles are also retained, whilst the sewage flows upwards between the two outermost cylinders and overflows. The heavier solids form a sediment in the outer cylinder.

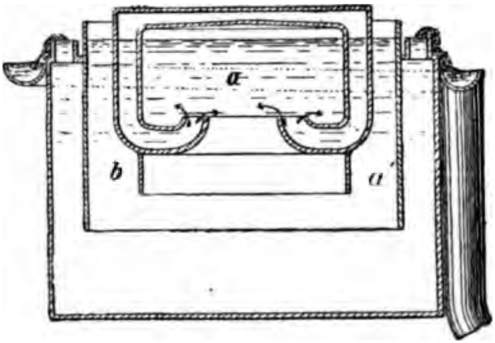


Fig. 36.—Kremer's Grease Extractor (Frankfort).

The apparatus shown in figs. 37 and 38, which was also invented by Kremer, is similarly constructed. It consists of an apparatus in which the course of the sewage and the separation of the grease are practically the same as in the extractor used at Frankfort. The sediment is removed for further operations by means of a worm conveyor. Fig. 37 shows, in longitudinal section, a form of Kremer's apparatus erected by the Berlin Company for Sewage Purification.

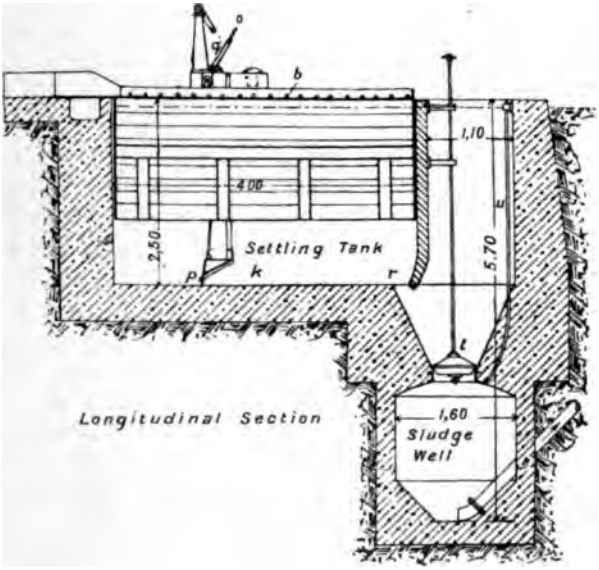


Fig. 37.—Kremer's Grease Extractor.

Two such plants were erected and tested at the Berlin Sewage Farm at Osdorf in 1903. On an area of 15 square yards the plant could deal with 200,000 gallons of sewage in twenty hours, yielding 5 lbs. of floating matter per 1000 gallons treated. This contained 86 per cent. of water and 6 to 9 per cent. of grease, the dried residue contained 44 to 49 per cent. of grease. If worked continuously, the plant could remove 50 per cent. of the suspended matter from the sewage; but if worked intermittently, and then dealing with only half as much sewage, the solids removed amounted to 70 to 93 per cent. It should be mentioned that the sewage had already passed through the detritus tanks at the pumping station, and was therefore deprived of its sand and heavier solids.

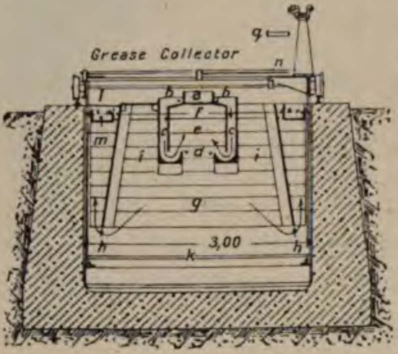


Fig. 38.—Kremer's Grease Extractor.

The calculations of the above firm are based upon Schreiber's investigations, according to which about two-thirds of an ounce of grease enters the Berlin sewers per head per day, and the Berlin sewage contains 0·010 to 0·026 per cent. of grease. The grease in sewage is estimated at 16 lbs. per head per annum; and since 40 per cent. (25 millions) of the population of Germany live in towns of over 5000 inhabitants, and of these 25 millions, 15 millions live in towns which are already sewered, the amount of grease in the sewage of Germany is very large. It may be estimated at about 100,000 tons per annum, and it has until now been practically all wasted. The problem of grease extraction is therefore regarded as important.

I do not doubt that the installation of simply constructed grease extractors will be profitable in the case of abattoirs and similar works; but the recovery of grease from ordinary town sewage will be expensive, unless the recovery is restricted to that portion which rises to the surface when the velocity of the sewage is reduced. In some English towns this method has been tried, and it could easily be adopted in all large towns; the grease thus recovered is readily bought by soap makers. John D. Watson of Birmingham, whose practical ability and unceasing energy are devoted to all questions relating to sewage treatment, adopts the view that the recovery of grease from town sewage should never be attempted with a view to financial success.

Where the conditions are such that the sewage need not be subjected to further treatment than by detritus tanks and screens, the comparatively small quantities of grease present in sewage need not give rise to nuisance. It appears more important, however, to separate the grease, as far as possible, when the sewage is to be subjected to a biological treatment, and, in the case of sewage farms, the grease deposited on the surface of the land is often detrimental to the treatment.

Settlement, Septic Action, and Precipitation.

Sedimentation.—From some of the results which have been published it might be inferred that detritus tanks and screening arrangements are capable of removing 50 to 60 per cent., or even more, of the suspended matters from sewage. Such inferences are not warranted, as will be shown in Chapter XI. Even with the very best constructed forms, 20 to 25 per cent. is the limit which can be attained. The remainder consists of fine particles which would pass through any mechanical screen, but which may be separated from the sewage either by reducing its velocity or by bringing it to rest for a period ranging from half an hour to several hours. Such a process is termed *settlement* or *mechanical sedimentation.* By such treatment it is not possible to obtain a perfectly clear effluent, even by allowing the sewage to stand for twenty-four hours or even longer. There still remain from 10 to 20 per cent. of the suspended matters in the sewage, and these are the cause of its turbidity.

Precipitation.—By the aid of certain chemical substances, termed *precipitants*, these remaining solids may be practically completely removed. The advantages and disadvantages of *precipitation*, as compared with simple sedimentation, will be found discussed on p. 97.

Septic Action.—The septic tank treatment may be regarded as a kind of sedimentation process. It has been lately adopted by many towns in connection with biological methods of purification. It has been already mentioned that sewage may be clarified by allowing putrefaction to proceed as far as possible, but practically this method cannot be carried to the extent of the disposal of all the suspended matter (see p. 86).

In this chapter only the principles will be discussed, according to which these three processes have been applied in practice, and their comparative merits and cost will be discussed later (Chapters X. and XI.).

D. Settlement.

Settling tanks should be so constructed that the current of the sewage is reduced as much as possible and as quickly as possible, and so that they can be easily manipulated, especially as regards the removal of sludge.

The earliest forms, as constructed in the coal districts of England, were simply the most primitive kind of holes dug in the earth ; the water simply flowed through them, and they received no attention. They were therefore generally full of sludge. The tanks constructed for English towns some decades ago were all intended to be used intermittently, and were constructed as precipitation tanks.

Theoretically, intermittent action, in which the sewage is allowed to come to rest, is more efficacious than continuous action, in which the sewage is allowed to flow continuously through the tanks, but continuous action has many practical advantages over the intermittent method of working. At each emptying and filling of the tank there is a danger of stirring up the sludge, which should therefore be removed each time the tank is emptied. This may be rendered unnecessary by the use of a floating outlet, which only allows the surface water to flow out (fig. 39). Intermittent action also causes a loss in the available head of the sewage equal to the height in the tank, and the time of filling and emptying are not utilised in the purification process. Moreover, Santo Crimp was able to show, in the case of London, where the tanks were originally designed for use on the intermittent system, that when the continuous process was adopted, without any other change whatever in the method of working, the volume of sludge obtained rose from 1380 to 4360 cubic yards per day —a result which would not have been anticipated on theoretical grounds, showing that the continuous was far more efficacious than the intermittent method of working.

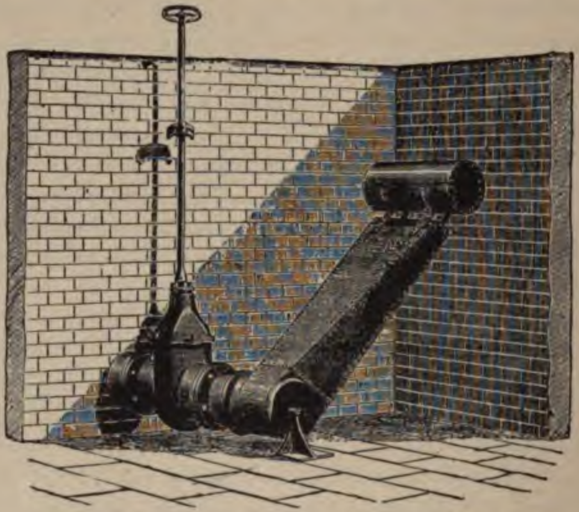


FIG. 39.—Apparatus for Emptying Settling Tanks.

In England, almost without exception, sedimentation tanks have been constructed rectangular. Scientific experiments as to the form most suitable for the sedimentation of the sludge seem to have been hardly carried out at all, and many of the English installations are of the form represented in fig. 40. The tanks are in the shape of a horse-shoe, or of several horse-shoes placed one after the other, and so arranged that the sewage passes through the various sections in turn. Several division walls are also built across each section.

The sedimentation tank, which is shown in longitudinal section in fig. 41, is a form which has also been much adopted in England. The bed of the tank slopes towards the inlet end, where a pump well (*b*) is provided. The sewage enters the tank over a weir (*a*), extending across the whole width of the tank; it then passes under a scum board (*c*) and over a submerged wall (*d*), again under a scum board (*e*) and over another submerged wall (*f*), before it reaches the outlet end of the tank, where it is discharged over a weir (*g*). The sludging of the tank is effected by opening holes (A) in the submerged walls, when the sludge gravitates to the pump well.

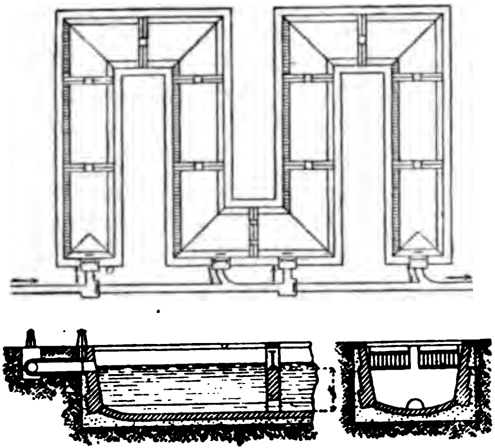


FIG. 40.—Horse-shoe Arrangement of Tanks.

Sedimentation tanks have also been constructed in the form shown in fig. 42. Here the sewage has to flow horizontally in a zig-zag path before it reaches the outlet. Another form of construction is depicted in fig. 43, in which several tanks are placed so that the sewage has to pursue a winding course in passing through them. The sludge is intended to collect in the side portions of the tanks, as shown in the figure.

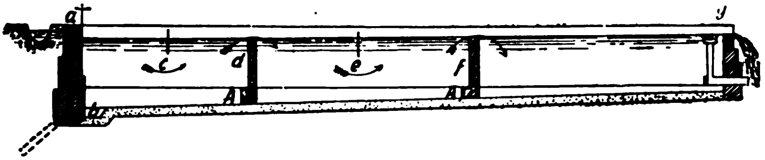


FIG. 41.—Sedimentation Tanks adopted in England. Longitudinal Section.

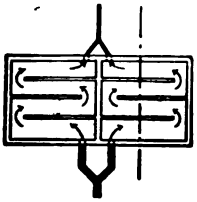


FIG. 42.—Sedimentation Tanks with Cross Walls.

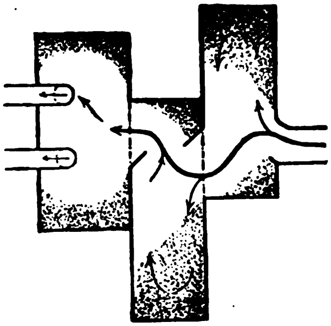


FIG. 43.—Arrangement of Sedimentation Tanks.

Lately, the general practice has been to adopt simple forms of construction, by which the sewage is brought to rest as quickly as possible, and in which the sludging is performed as easily as possible.

At first little provision was made for removing the sludge from the tanks. Putrefaction set in, and gases were evolved which raised the sediment in lumps, and these were discharged to the stream. The effluent from the tanks also acquired a putrid character from its contact with the putrefying sludge. Such nuisances were the cause of the opinion held about twenty years ago that sedimentation would have to be abandoned, and tanks were then used as precipitation tanks. During the last decade, however, the conviction has gained ground that in many cases simple sedimentation without the addition of chemicals is quite sufficient, and that it possesses advantages over chemical precipitation, if the sludging of the tanks is properly attended to and the tanks thoroughly cleaned out as soon as the sediment begins to putrefy. For, if sewage is placed in tanks containing putrefying sludge, a few hours suffice to render the sewage putrid. In hot weather it may be necessary to sludge the tanks out every two or three days, whilst in winter they will go eight or ten days. For this reason it is evident that the arrangements for sludging out should be as simple as possible.

Sedimentation Experiments.—The most valuable experiments on sedimentation have been carried out during the last few years by Bock and Schwarz at Hanover, and continued by Steuernagel at Cologne. These experiments, together with the observations of Schmidt on the direction of the currents in the tanks at Oppeln, have cleared up all the more important points relating to sedimentation processes.

Previous to the Cologne experiments, the bed of the sedimentation tank was often made to slope towards the outlet end. Steuernagel demonstrates, by means of fig. 44, the absurdity of such a construction. If the bed of the tank slopes towards the outlet end, the sediment, which is chiefly deposited at the inlet end, reduces the already smaller cross-section of the tank at the inlet end, and thus facilitates the stirring up of the solids by the current of the sewage, as well as the *possible* redissolving of the solids.

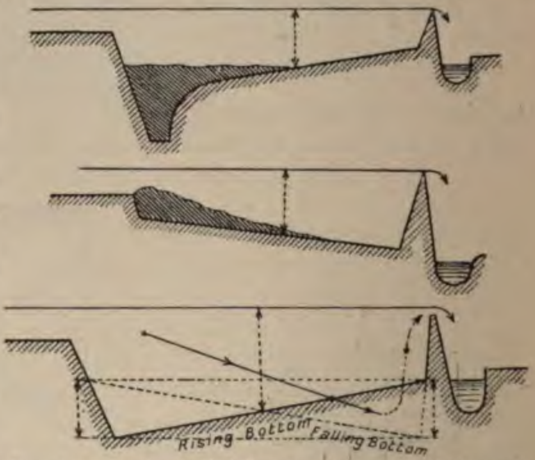


Fig. 44.—Good and Bad Construction of the Bottom of Sedimentation Tanks, according to Steuernagel.

The experiments at Hanover and Cologne have also been of importance in disposing of the old belief that it is absolutely necessary to reduce the velocity of the current of sewage through sedimentation tanks to $\frac{1}{8}$-inch or $\frac{1}{12}$-inch per second, or even less. Even so late as 1894, a Ministerial Order stipulated that the city of Cologne should construct sedimentation tanks in such a manner as to reduce the velocity of the sewage through them to $\frac{1}{6}$-inch per second.

In 1899, Bock and Schwarz worked settling tanks, 54 and 81 yards long, at such rates as to give velocities ranging from $\frac{1}{6}$-inch to $\frac{4}{5}$-inch per second. They demonstrated that the night sewage deposited no sediment, but at times carried away some of the solids which had been deposited from the sewage produced during the day. At a velocity of $\frac{1}{6}$-inch to $\frac{1}{3}$-inch per second, they succeeded in depositing 55·7 per cent. of the suspended matter from the day sewage in the shorter of the above tanks and 61·5 per cent. in the longer tank. On increasing the velocity to $\frac{4}{5}$-inch per second, the result produced by the longer tank was only reduced to 57 per cent. The same sewage, on standing for twenty-four hours, deposited 88·8 per cent. of its suspended matter, and 11·2 per cent. consisted of very fine particles which would not deposit. Settlement for an hour and a half produced practically the same result as could be obtained in three to four hours, depositing 68·1 per cent. of the suspended matter.

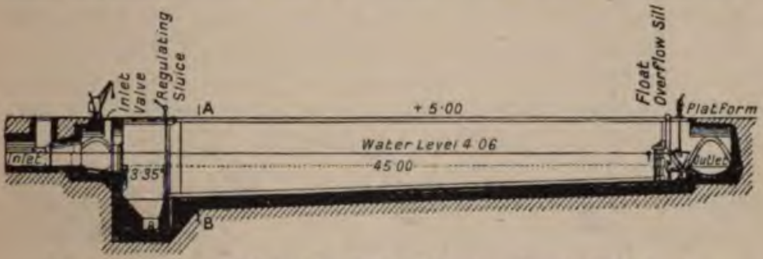


Fig. 45.—Experimental Settling Tank (Cologne). Longitudinal Section.

These investigations were followed in 1900 by those of Steuernagel, who experimented in the tank, an illustration of which is given in fig. 45. Since this tank may, according to our present knowledge, be regarded as a model for all sedimentation tanks, a short description will be given here. After passing a detritus tank and screening apparatus, the sewage enters the sedimentation tank by two pipe inlets, not over a weir. At the inlet end the bed of the tank is hollowed out to form a pump well. From the pump well the bed of the tank, 49 yards long, rises gradually towards the outlet end. After passing the pump well, the impact of the sewage is broken by means of wooden guards, which also serve to equalise the distribution of the sewage throughout the cross-section of the tank. At the outlet end a weir is provided, the height of which may be regulated. Experiments were carried out in this tank with velocities of the sewage varying from ⅙-inch to 3 inches per second.

The treatment of the night sewage at Cologne yielded results similar to those obtained at Hanover; the effluent from the tank contained at times more suspended matter than the inflowing sewage. It was therefore thought advisable not to use the tank during certain hours of the night. During the daytime, with a velocity of ⅙-inch per second, 72·31 per cent. of the suspended matter in the sewage was deposited; on increasing the velocity to five times this amount, nearly the same percentage of solids was removed, viz., 69·08, and on again doubling this velocity, 58·9 per cent. of the solids was deposited.

The effluent obtained after passing the sewage through the tank at a velocity of ⅙-inch per second deposited a further 11·7 per cent. of the solids on standing for twelve hours, thus still leaving 15·99 per cent. in suspension.

These results appear more satisfactory than those obtained at Hanover, especially when we consider that the Cologne tank was the shorter. The variations in the sewage of different towns may be the cause of differences in the separation of suspended matters, but Steuernagel believes that the better results at Cologne are due to the more suitable construction of his tank. He lays special stress upon two factors, which had already been recognised in England (see fig. 41), viz., the position of the sludge well near the inlet end of the tank and the upward slope of the bed of the tank towards the outlet end.

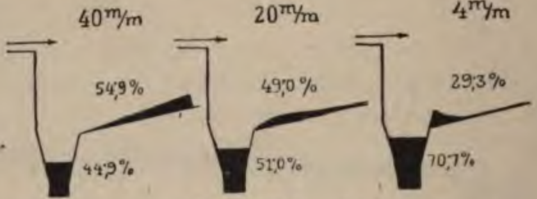


FIG. 46.—Action of Pump Well at Cologne with various Sewage Velocities.

In the Cologne experiments, with a velocity of ⅙-inch per second, 70·7 per cent. of the sludge settled into the pump well and 29·3 per cent. over the remainder of the tank bottom (see fig. 46). At five times this velocity the figures were 51 per cent. in the pump well and 49 per cent. over the tank bottom, and on again doubling this velocity the figures were approximately 45 and 55 per cent. At higher velocities the solids were carried over the pump well and on to the bottom of the tank. Steuernagel concludes that long tanks are necessary for high velocities, and that shorter tanks suffice for lower velocities.

As a result of one day's observations in each case, Steuernagel obtained the following amounts of sludge per 1000 gallons of sewage for the different velocities:—

Velocity (inches per second).	Sludge (gallons).	Analysis of Sludge.	
		Moisture (per cent.).	Dry Residue (per cent.).
$\frac{1}{6}$	4·040	95·57	4·43
$\frac{5}{6}$	2·474	92·87	7·13
$1\frac{2}{3}$	1·838	91·34	8·66

It will be seen that a gallon of the sludge obtained at the highest velocity contains about twice as much solid matter as a gallon obtained at the lowest velocity. If, by the use of these figures, we compare the results obtained at the two velocities, on the assumption that the specific gravity of the sludge is the same in both cases, we find that the amount of solid matter retained at the higher velocity is almost as great as that retained at the lower velocity, which is ten times less. Moreover, the sludge obtained at the higher velocity is easier to deal with than that obtained at the lower velocity, and the small excess of solids which are carried forward into the stream at the higher velocity consists of very fine particles, which are quickly distributed throughout the water of the stream. Whether the same results would have been obtained if the experiments had been continued for several days has not been decided by Steuernagel. Further experiments would be very useful, for they might lead to the conclusion that a short period of sedimentation is able to remove the finer suspended solids, of a less diameter than, say, $\frac{1}{5}$-inch, more cheaply than screens, which, in their construction, maintenance, and working, are costly.

The practical importance of the above experiments for Cologne was shown by the fact that the authorities withdrew the expensive requirements which they had formulated, and permitted the discharge of the Cologne sewage into the Rhine after the removal, by means of suitable screening apparatus, of suspended matters of a diameter down to $\frac{1}{8}$-inch.

The direction of the sewage currents at various depths in the tanks has been investigated by Bock and Schwarz. They employed small glass bottles, and sank these to depths varying from 1 to 6 feet. Their results showed that the sewage moved sometimes upwards, sometimes downwards, and sometimes towards the sides of the tanks, with a velocity two to three times as great as the calculated average velocity through the tank.

These sources of error were later demonstrated in a very clear manner by Schmidt at Oppeln. By addition of a colouring matter (uranin) he showed that at the cooler periods of the year the warm sewage flowed on the top of the cooler contents of the tank. Variations in temperature cause variations in the flow of the sewage, as depicted in figs. 47 and 48. The dotted lines show the direction taken by the entering sewage, according as it is warmer or colder than the contents of the tank.

With regard to the quantity of sludge produced by sedimentation and the possibility of its utilisation, further data will be given in Chapter XI.

Loss of Head.—Deep Tanks.—Above, it was stated that the continuous method of working sedimentation tanks is more advantageous than the intermittent, in that it does not involve a loss in the head of sewage. This advantage applies only so far as the sedimentation process itself is concerned. If we also consider the disposal of the sludge, the top water in the shallow tanks above described, when used on the continuous principle, must be let off before the sludge can be removed. The volume in question is indeed only a small fraction of the total volume of sewage, and hence it does not involve the installation of a large pumping plant.

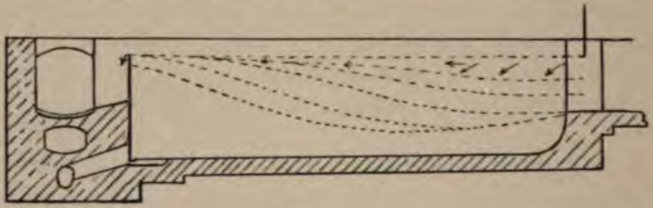


FIG. 47.—Flow of Sewage through Tanks on Cold Days, according to Schmidt.

Several engineers have attempted to construct sedimentation tanks for continuous use, so as not to require emptying before removing the sludge. These have taken the form of wells or towers, and have been used more in conjunction with chemical precipitation than for simple sedimentation. Eminent experts have even declared that deep tanks are only applicable when the sedimentation process is accelerated by means of precipitants. A few years ago, however, Mairich demonstrated practically, that good results could be obtained by using deep tanks, even without the aid of precipitants, thus showing that the opinion expressed in the preceding sentence, which had been held for years, is not tenable in every case. Deep tanks have, however, certain disadvantages which will be mentioned later, so that it appears doubtful whether they will be much used in the

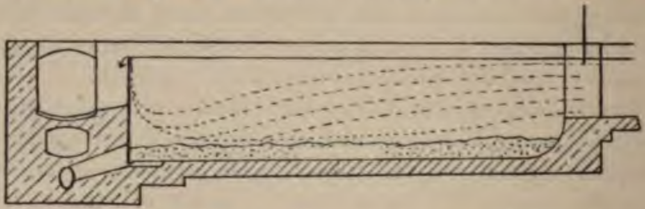


FIG. 48.—Flow of Sewage through Tanks on Warm Days, according to Schmidt.

future for the separation of suspended matter from crude sewage, especially as forms of construction have lately been devised, and are said to have given satisfaction, by which the sediment may be removed from shallow tanks without first removing the top water (see p. 79). This is the only point in which deep tanks are more advantageous than shallow ones, unless the consideration, raised by various authors, that the former occupy less space than the latter must be regarded as important.

For the after-treatment of the effluent from biological filters, a matter which at the present time is exciting a good deal of interest (see Chapter VIII.), deep tanks may be more advantageous than shallow ones and hence the main types will be shortly described here. It must not be forgotten, however, that some of these forms of construction are totally unsuitable for simple sedimentation, and are intended for use in conjunction with chemical precipitation, a process which will be dealt with later.

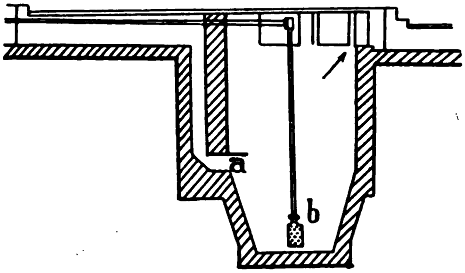


FIG. 49.—Müller and Nahnsen Tank (Halle).

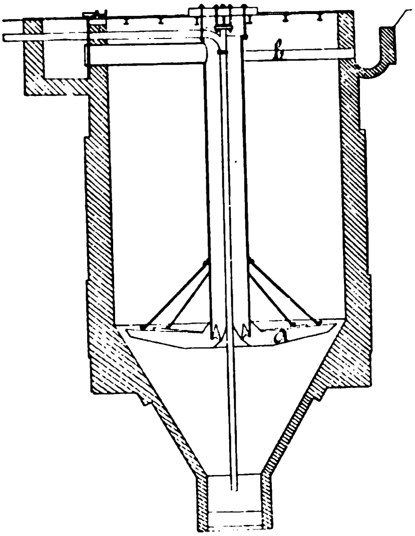


FIG. 50.—Kniebühler's Tank (Dortmund). Cross Section.

In 1886, Müller and Nahnsen constructed at Halle the form of tank shown in fig. 49. The sewage first passes through a detritus tank, and then enters the deep tank, which is about 25 feet deep, at a point (*a*) about 8 feet from the bottom. By suitably reducing the velocity of the sewage it is intended that the solid matters shall sink to the bottom and the sewage flow upwards and overflow, possibly into a second deep tank. The sludge is pumped from the point (*b*) without interfering with the working of the tank.

Soon afterwards the tank shown in figs. 50, 51, and 52 was constructed by Kniebühler at Dortmund. It is about 45 feet deep, and differs from the Halle tank chiefly in the attempt which is made to distribute the sewage evenly throughout the cross-section of the tank by means of horizontal radiating channels (fig. 51). The sewage was also intended to rise through a thin filter and to overflow into channels placed all over the surface of the tank (fig. 52). The Dortmund tanks were so constructed that, on the days when they had most work to perform (slaughtering days), the sewage, after treatment with lime and sulphate of alumina or copperas, rose in the tank with a velocity of 0·022 inch per second, thus remaining in the tank for 1¾ hours.

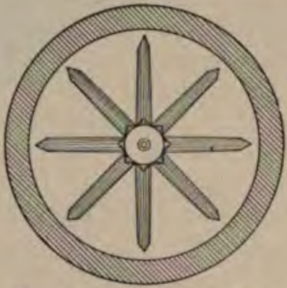


FIG. 51.—Kniebühler's Tank (Dortmund).

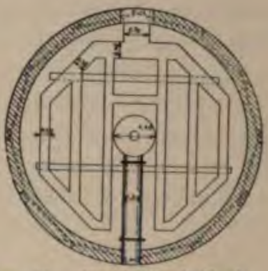


FIG. 52.—Kniebühler's Tank (Dortmund).

At Stargard and Neustadt in Upper Silesia, Mairich has constructed tanks very similar to the Dortmund tanks. They do, however, possess distinguishing features. The Neustadt tanks (fig. 53) are 22 feet deep, and the sewage enters through twelve tangential pipes (*a*) leading horizontally towards the centre of the tank at a point 14 or 15 feet below the surface. Inside the tank the inlet pipes take the form of half pipes

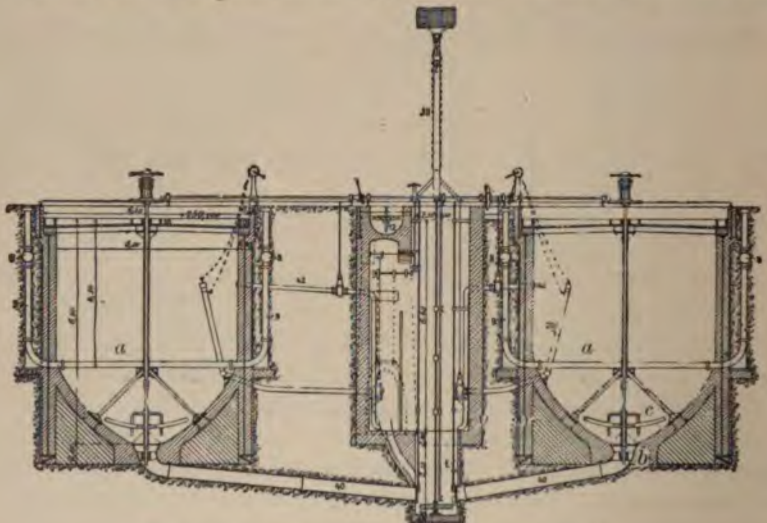


FIG. 53.—Mairich's Tanks (Neustadt, Upper Silesia).

BOARD OF ESTIMATE AND APPORTIONMENT

or inverted channels, as in the Dortmund tank. The Stargard tanks (fig. 54) are so constructed that with an upward velocity of 0·02 inch per second the sewage remains in the tank for two hours. The sewage leaves the tank by means of radiating channels at the surface; but whereas in the Dortmund tank the sewage overflows into the channels, in the Stargard tank it enters by means of holes. The sludge is removed from the Neustadt tanks by opening the valve (*b*), after first stirring up the contents of the bottom of the tank by means of the stirrer (*c*).

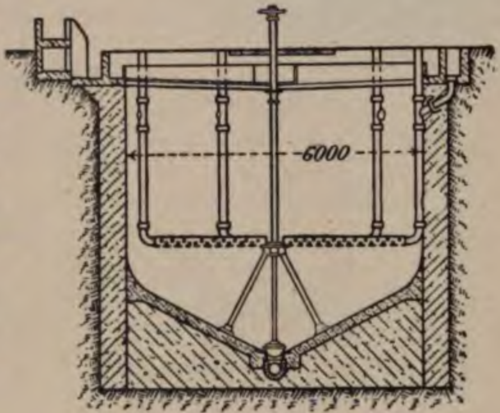


Fig. 54.—Mairich's Tank (Stargard).

Later, Mairich constructed his tanks smaller, and used more of them; at Ohrdruf, with 6000 inhabitants, 28 tanks were constructed; at Langensalza, with 13,000 inhabitants, 40 tanks; and at Guben, with 33,000 inhabitants and a daily flow of sewage equal to two million gallons, 84 tanks are in use. These small Mairich tanks, with a working height of about 8½ feet and covering 6 square yards each, are more like the Dortmund tanks than Mairich's older forms, as regards the manner in which the sewage is led into the tank. The form used at Guben is illustrated by figs. 55 and 56.

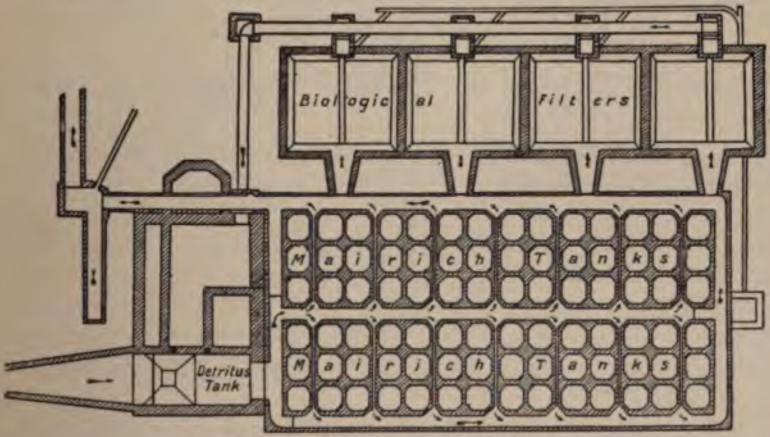


Fig. 55.—Mairich's Tanks (Guben). Plan.

At Birmingham, Watson recommends the use of deep tanks in preference to shallow ones for certain purposes, more especially because the sludge is more easily removed from deep tanks. The effluents from his septic tanks are passed through deep tanks after passing along a large long channel. Besides this, Watson sends the effluent from his biological filters through deep tanks, "Birmingham Separators" (fig. 57), for the removal of the flocculent matter which it contains. Deep tanks seem to be specially suitable for the after-purification of the effluents from biological filters. Watson is of the opinion that the cylindrical portion of the Dortmund tank, which is otherwise similar in construction to the Birmingham Separator, is of little use, since the velocity of the sewage in this portion is uniform. He attaches more importance to the conical portion of the tank, in which the velocity of the sewage diminishes as it rises, and he has therefore made his separators largely of this shape. The small upper cylindrical portion is chiefly to facilitate the connection of the inlet and outlet pipes. In Birmingham the sludge is not removed by pumps or valves from the bottom of the tank, but is driven up a pipe, after opening a valve, by the pressure of the contents of the tank, to such a height that it can freely flow away.

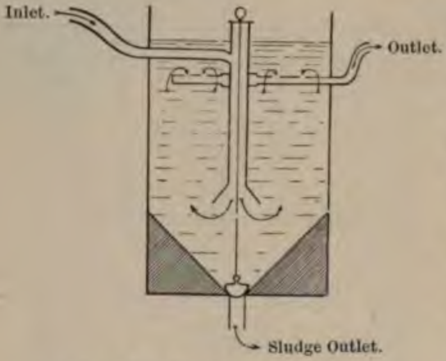


FIG. 56.—Mairich's Tank (Guben). Cross Section.

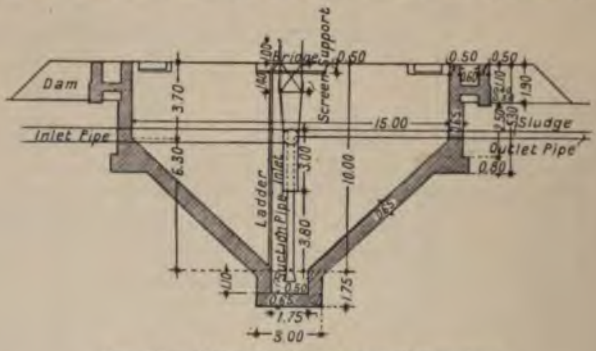


FIG. 57.—Watson's Birmingham Separator.

This somewhat long description of deep tanks has been given chiefly on account of their application to the removal of the solids from the effluents from biological filters; in such a case the solids are usually flocculent and not so liable to putrefactive decomposition as the solids in crude sewage. Even when constructed as simply as the Dortmund tank, it is said to be difficult to keep the tanks clean enough to prevent septic action when crude sewage is dealt with. Some of the solids adhere to the walls and constructive portions of the tank, and there decompose, thus giving the effluent a septic character even when the sewage only remains in the tank a short time. It will thus be seen that simplicity of construction is most important when considering the treatment of crude sewage, whether in shallow or deep tanks.

From theoretical considerations, Dervaux has come to the conclusion that the action of a tank is directly proportional to the surface which is exposed to the sewage, and has therefore constructed a tank of the form shown in fig. 58, in which he has inserted a large number of conical surfaces. Travis has lately recommended a somewhat similar construction, which will be dealt with later (see p. 90). Dibdin's slate beds also fulfil a somewhat similar purpose; they also will be described later.

Experiments which I have carried out with the object of determining which is the most suitable method of allowing sewage to enter deep tanks, and whether the introduction of obstacles to aid the deposition of the suspended matter is advisable, have shown that the latter is undoubtedly the case.

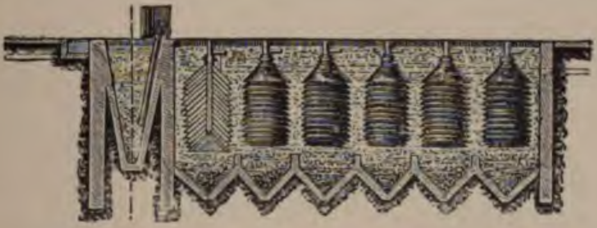


FIG. 58.—Dervaux's Apparatus with Conical Surfaces.

The adoption of certain measures to ensure the sewage passing along definite paths or channels may be advisable in the case of effluents from biological filters. I hardly think, however, that the apparatus of Dervaux or similar forms will be suitable for the purpose, since the already narrow channels along which the sewage has to pass are made still narrower by the deposited solids. This increases the pressure of the sewage, which then forces a way and carries along with it the solids which have previously been deposited. In this respect the apparatus of Travis is better than that of Dervaux.

For the treatment of crude sewage, however, the most important points in the construction of tanks seem to be simplicity, avoidance of constructive parts to which putrefactive solids can adhere, and walls built as smoothly as possible.

Removal of Sludge.—Of deep tanks it is reported that the advantage to be gained by the removal of the sludge without interfering with the action of the tanks is more than counteracted by the large amount of water which is removed along with the sludge. With careless management, such a disadvantage must certainly be reckoned with, and with some forms of tank it can scarcely be avoided. Experience has also taught me that if the sludge is not regularly removed, but is allowed to accumulate, then deep tanks are specially susceptible to the influence of changes in the volume of sewage, such as occur on wet days. The sludge is then easily stirred up and washed out of the tank. With careless management such sludge may be in a septic condition, and thus give rise to nuisance.

As regards cost, shallow tanks are generally cheaper than deep, and are more easily attended to. I have no doubt that they will be everywhere preferred as soon as it is possible to remove the sludge from them without previously running off the top water. In Bolton, experiments in this direction have been made with an apparatus constructed by Fidler (fig. 59). In this illustration the apparatus is shown moving the sludge from the flat bottom of a deep tank towards the sludge valve in the centre of the tank. It can, however, be used for rectangular shallow tanks (fig. 60). It has already been mentioned that the solids are removed in a similar manner from the Hamburg detritus tanks by means of a dredger. But if it should be found that such sludge collectors are not suitable for all purposes, it is quite conceivable that suitable movable forms of apparatus could be devised for the removal of sludge from the bottom of shallow tanks and for keeping the tanks clean without previously running off the top water. The old method of sludging shallow tanks at Bolton is illustrated by fig. 61; and a new apparatus, which is used as well as the one shown in fig. 60, is illustrated by fig. 62. With this apparatus it is possible to remove the sludge from tanks over a hundred yards long in less than a quarter of an hour.

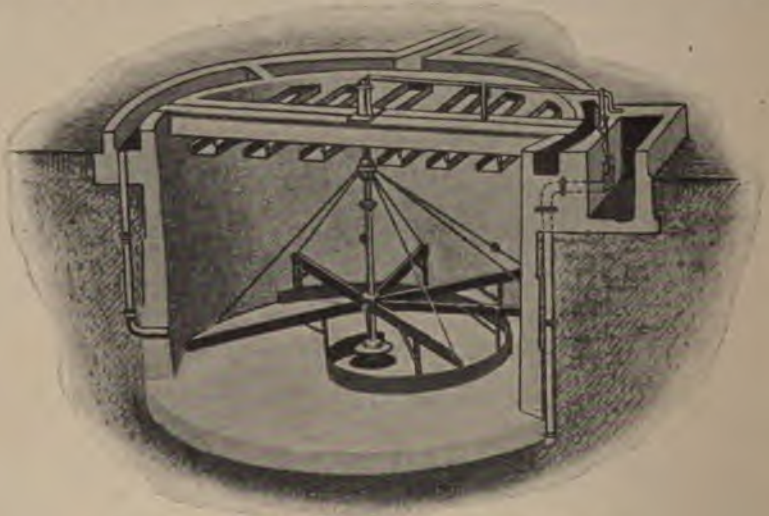


FIG. 59.—Fidler's Sludge Collector (Ham, Baker & Co.).

At Barmen-Elberfeld the bottom of shallow tanks has been constructed with conical depressions, as shown in fig. 58, so that the sludge can be removed in the same manner as from deep tanks. I

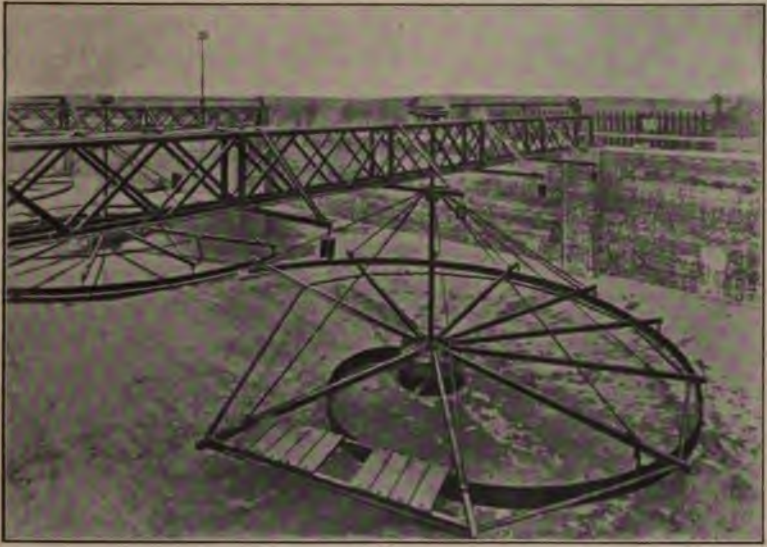


FIG. 60.—Fidler's Sludge Collector for Rectangular Shallow Tanks (Ham, Baker & Co.).

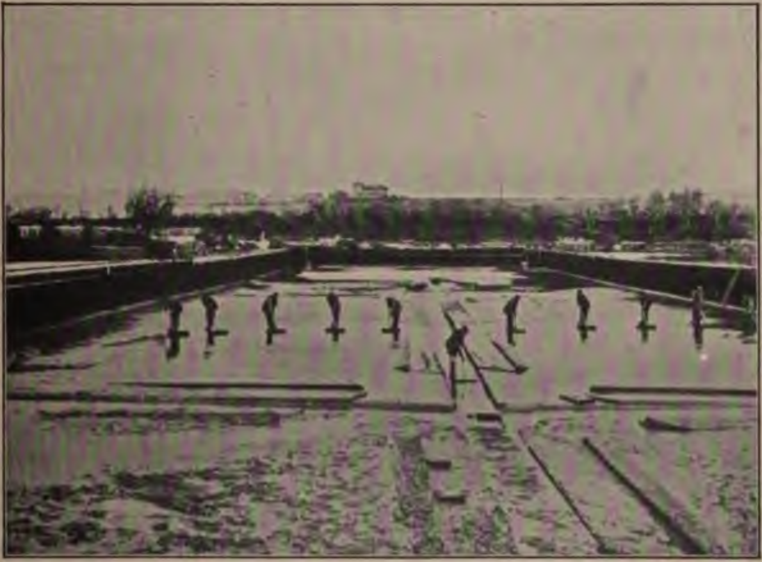


FIG. 61.—Removing Sludge from Sedimentation Tanks. Old Method (Bolton).

do not think, however, that this will be a satisfactory solution of the difficulty.

In order to avoid the expense which is generally involved in excavating for the construction of deep tanks, towers have been erected. This simply means that the tanks are above instead of below ground. This form of construction has been very largely used by the firm of Rothe-Röckner, an illustration of whose apparatus, as applied to Degener's lignite process, is given in fig. 63. The sewage enters at the bottom of the cylinder by means of tangentially arranged pipes (*a*), rises in the cylinder, which has been evacuated by means of an air pump, and is then siphoned over into the effluent channel (*b*). The sludge is mechanically moved to the lowest point of the cylinder and then removed by pumping.

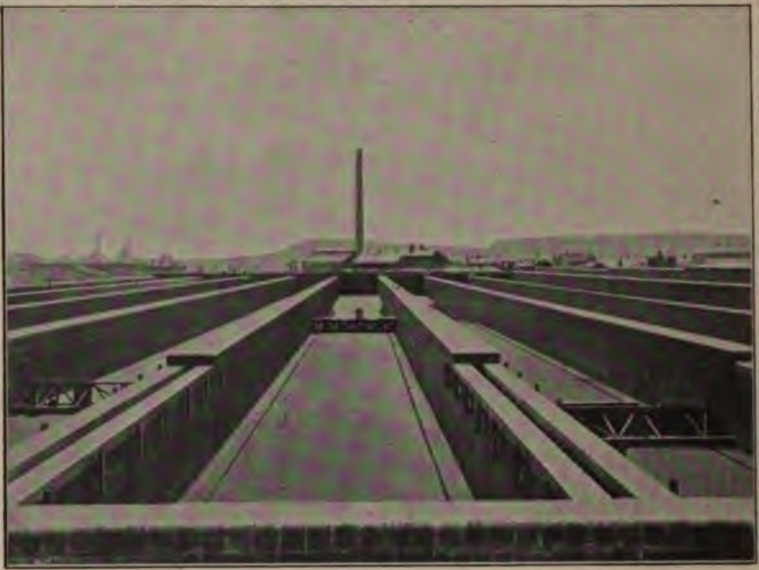


FIG. 62.—Ashton's Apparatus for removing Sludge from Sedimentation Tanks (Bolton).

E. Septic Treatment.

Since 1895 a modification of the sedimentation process, the septic tank treatment, has been adopted by numerous towns, as a result of experiments which were carried out at that time by the city engineer of Exeter, Donald Cameron. The septic tank treatment differs from sedimentation chiefly in the fact that the sludge is not regularly removed before putrefactive decomposition sets in, but is allowed to remain for months or even for years in the tanks.

It has already been mentioned that the sedimentation process was at first often worked in this manner; not, however, intentionally, but on account of bad management. The consequence was that the gases evolved from the decomposition of the sludge carried some of the sediment upwards, and this escaped in the effluent, to which it gave a septic character. In the septic tank suitable arrangements have been made to reduce the escape of septic sludge to a minimum, but the septic character of the effluent is

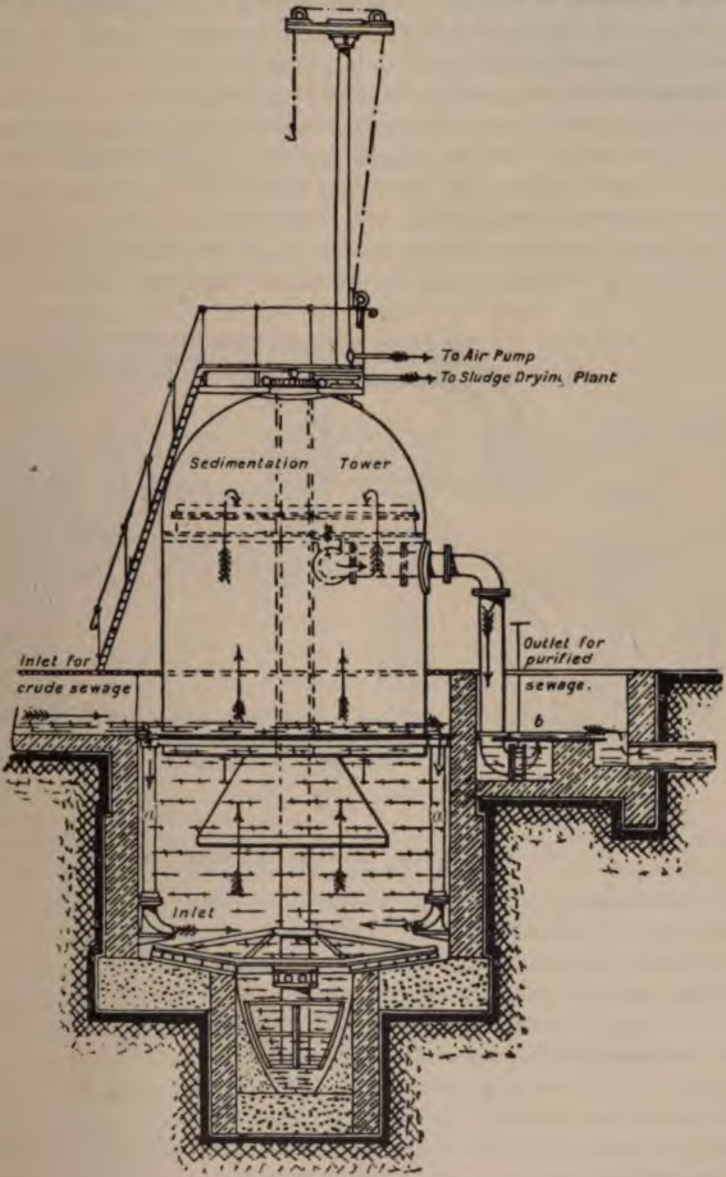


Fig. 63.—Rothe-Röckner Tower.

unavoidably associated with the process. Hence this treatment cannot be regarded as a complete method of sewage purification. At one time it was thought otherwise, and for years before Cameron's experiments the process played such an important, not to say fatal, rôle that a short historical sketch of its development appears to be necessary.

History of Septic Action.—About the middle of the seventeenth century putrefaction was ascribed to the action of microscopic organisms. At that time these were not termed bacteria, but "microscopic worms." In 1773 Linné sought "the cause of fermentation and putrefaction" among microscopic living things. In 1762 Plenciz found innumerable "animalculæ" in all putrefying matter, and ascribed the origin of putrefaction to "a microscopic wormy mass." In 1863, in conjunction with experiments by which he had demonstrated that fermentation was to be regarded as a process due to the action of micro-organisms, Pasteur recommended the investigation of all processes similar to the decomposition of sugar, organic acids, albuminoid substances, etc., and of all processes connected with nitrification, in order to ascertain what part is played in these processes by micro-organisms.

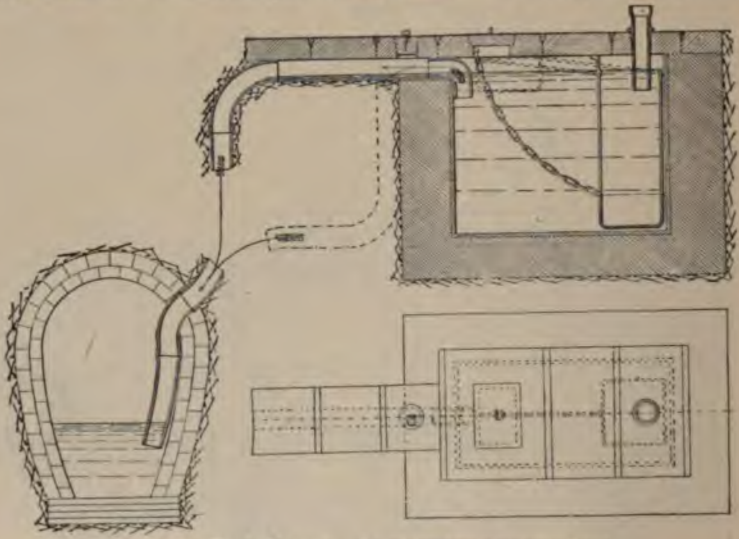


Fig. 64.—Fosse Mouras. La vidangeuse automatique.

About 1860, Louis M. Mouras, of Vesoul, constructed the cesspool shown in fig. 64. It was so arranged that the house connections and the outlet pipe leading into the street drain were always beneath the surface of the liquid, so that the gases evolved during the putrefactive changes going on in the cesspool should neither gain access to the dwellings nor to the drains. A vessel attached to a chain was provided for the retention of the larger solid matters. All the excrementitious matter and other putrescible solids were said to be liquefied in the tank by anaerobic fermentation with the production of only a slightly turbid liquid. The introduction of these cesspools in Paris was diligently advocated by the Abbé Moigno, but the results obtained from them were not very satisfactory. Later, however, they were adopted in various places under the name of *fosses Mouras*. In Bordeaux, the city engineer stipulated that they should consist of two compartments, and be provided with a gas outlet pipe, fig. 65; for, contrary to the expectations of the inventor, it had been found that gas collected over the liquid, and occasionally attained such a pressure that the level of the liquid was depressed to the mouth of the outlet pipe, with the result that the floating solid matters were ejected. French hygienists, among them Richard, have stated that, according to their observations, the *fosses Mouras* are, to say the least, perfectly useless. Nevertheless, under various names and with some slight modifications, they have again and again been brought forward as new inventions. In Italy and Switzerland they have been rejected by hygienists after careful investigation. Then, under the name of "biological purification plant for fæcal matter," they were introduced into Germany, where they were adopted in a good many places, partly on account of promising reports, but chiefly because they were confused with the artificial biological processes of sewage treatment which rose into prominence about that time. Reports by engineers and sanitarians have also not been wanting in which it has been stated that sewage could be converted in such an apparatus into a non-putrescible liquid. The mistake has only been recognised after trial, and much money has been uselessly spent on this kind of apparatus. All experiments go to prove that sewage cannot be rendered non-putrescible in practice simply by septic action, although theoretically it may be possible (see p. 30). It should have been mentioned that, in 1878, Alexander Müller applied for patent rights for a process in which waste waters were biologically treated in septic tanks, from which air was excluded, and to which yeast and other fermenting substances could be added, if necessary. But Müller did not regard the effluents from such septic tanks as purified,

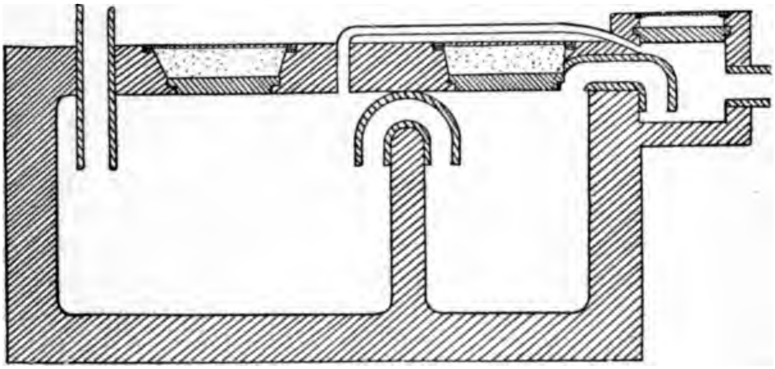


FIG. 65.—Fosse Mouras (Bordeaux).

and stated that they should be filtered or used for irrigation purposes. Cameron also did not regard the septic treatment as a final process, but only as a preliminary to biological filtration. His intention was to separate the solid matter from the sewage and reduce its quantity by the action which takes place in the septic tank. The promising reports on the results of his experiments quickly attracted the attention of the whole civilised world. The process was first taken up in England and then in other countries at a rate which is unequalled in the history of sewage purification.

Various authors maintained that it was impossible to purify sewage on artificial biological filters without first submitting it to septic action; and from various quarters reports were to hand to the effect that the solid matters in the sewage were entirely digested in the septic tanks. At first both these views had many upholders, but the Hamburg experiments were the first to show conclusively that artificial biological purification is not aided, but hindered, by first giving the sewage a septic character. The question as to what value is to be attached to the diminution of sludge which takes place in the septic tank is still a matter of keen debate. At first it was maintained that the sludge was entirely liquefied and gasified; then, that its volume was reduced by 50 per cent.; and, as a result of the most recent investigations of which I am aware, it is stated that the amount of sludge is not reduced by more than 9 per cent.

Advantages and Disadvantages of Septic Treatment.—I shall now attempt to place on record all the reliable data in our possession, which will enable us to assign a proper value to the advantages and the disadvantages of septic treatment, for both do undoubtedly exist. The advantages are: (1) The separation of the solids; (2) the uniform mixture to be obtained from sewage very variable in composition; (3) the preparation of the sewage for biological after-treatment; (4) the utilisation of the gases from the septic tank; (5) the diminution of the amount of sludge; (6) the septic sludge is more easily drained; and (7) the injurious action on pathogenic organisms. The disadvantages which have been urged are: (1) The foul smell of the effluent; (2) the increased difficulty of biological after-treatment; (3) the corrosive action of the septicised sewage on cement; and (4) the injury caused to fish-life, due to the large quantity of sulphuretted hydrogen present in the effluent from septic tanks.

Scum.—Sedimentation is not so easily attained in septic tanks as in settling tanks. As soon as the sediment becomes septic, it is carried upwards by the gases which are liberated. These gases escape at the surface of the liquid and the solids again begin to fall. This increases the danger of their being carried out along with the effluent, but this danger can be diminished by using floating scum boards or similar arrangements so that large particles do not escape. The sludge which thus collects on the surface forms a scum, which sometimes assumes quite a tenacious leathery character. So far as I have been able to observe, this tenacity of the scum appears to be due to the growth of vegetable moulds, which form a complete net-work throughout the scum. The commonest forms are *Pilobolus œdipus*, recognised by its brown spores, and a red fungus, *Peziza omphalodes*, which is found on most dung heaps. The scum, which consists of plant remains, paper, hair, fat, etc., is matted together by the hyphæ of these fungi, and thus converted into a tough mass in which all kinds of worms—earthworms, *Lumbricidæ*, and the larvæ of insects (especially *Psychoda phalænoides*)—are to be found. At certain seasons of the year the moulds die, with the result that the scum breaks up and sinks in small pieces. In some places, as at Leeds, it has been observed that the amount of suspended matter in the effluent from septic tanks shows seasonal variations, and this is probably due to changes in the vegetation of the scum. Rain is also said to cause the scum of open septic tanks to break up. The sludge which falls from the scum, in the form of a fine crumbly earthy matter, is no longer putrescible.

The scum is always thickest in septic tanks which receive sewage from which none of the suspended matter has been removed by means of detritus tanks or screens. Sewage which does not contain fæcal or similar easily decomposable matter generally forms only a slight scum. In covered septic tanks, too, the vegetable moulds do not grow with the same intensity as in open tanks, and hence the scum does not become so tough, but the nature of the sewage has more influence on the scum than whether the tanks are open or closed. Scum has been observed in *fosses Mouras* over a yard in thickness and of a solid waxy consistency, and it has even been the cause of serious trouble by stopping up the inlet and outlet pipes. The influence of climate upon the scum does not appear to be very marked. In the case of towns quite close to one another, scum half a yard thick may sometimes be observed at one place, whilst it is almost entirely absent from the septic tanks of a neighbouring town. In time, the surface of the scum often becomes of a crumbly earthy character, and grass and other vegetation flourishes. The scum does not smell, and serves to prevent the spread of foul smells from the contents of the tank; but even without the formation of much scum, septic tanks do not give rise to the nuisances from bad odours which it was at first feared they would do. For example, at Birmingham the open septic tanks, which have very little scum, cover an area of over 26,000 square yards, and yet villa residences have been erected only half a mile distant. A row of houses has been erected only a quarter of a mile distant from the tanks.

Septic Tank Effluents.—From what has already been said, it will be seen that a calculation of the sedimentation effected in septic tanks is much more difficult than in the case of settling tanks. Strictly speaking, reliable data can only be obtained by using the method adopted by Calmette at Madeleine near Lille. He passed a fraction of the sewage to be treated through a separate tank, and treated the effluent from the septic tank in a similar manner, in order to obtain reliable average samples. The close agreement, however, which is to be found in the various analytical data which have been published, justifies the drawing of conclusions which are sufficiently accurate for all practical purposes. At Leeds the solid matters removed from the sewage by the septic tanks amounted on the average to 69 per cent.; at Manchester to 61·5 per cent.; at Birmingham to 60 per cent.; at Hamburg to 71·3 per cent.; at Exeter to 56 per cent.; in Massachusetts to 61 per cent.; and at Leicester to 60 or 70 per cent. No great error would therefore be made in stating that septic tanks are able to remove 60 or 70 per cent. of the suspended matters from town sewage, and that by careful management 70 per cent. can be removed. This result may be considered satisfactory, when we remember that even under the most favourable circumstances not much more than 80 per cent. of the suspended matter can be removed by sedimentation. The period during which sedimentation takes place is not of such great importance. By allowing the sewage to remain for twelve hours in the septic tank, equally good results have been obtained as with twenty-four and forty-eight hour periods. Six hours produced the same sedimentation effect. A two-hour period in the Hamburg experimental septic tank only reduced the suspended organic matter in the sewage by about 30 per cent. The sedimentation is not affected by the tanks being open or closed. The above remarks only apply to domestic sewage or town sewage of normal composition. A very slight acid reaction of the sewage is sufficient to materially hinder the septic process.

Equalisation of Sewage.—As regards the equalisation of the composition of the sewage, septic tanks do not possess any advantage over settling tanks. I have not, however, been able to convince myself that this equalisation is of such importance for biological treatment as some authors would have us believe, especially if we are dealing with domestic or normal town sewage. It is different, however, for towns such as Manchester, where large quantities of trade refuse are produced, and where this is difficult to treat or is partly acid and partly alkaline.

Decrease of Dissolved Organic Matter. Production and Removal of Sulphuretted Hydrogen.—Opinions still differ on the question as to how far solids in solution are removed by septic treatment. After years of experiment, Dzierzgowsky has come to the conclusion that the dissolved organic matter is not appreciably reduced in the septic tank. Other authors have come to the conclusion that the oxygen absorbed and the organic and albuminoid nitrogen figures are reduced 60 per cent. or more in the septic tank. At Leeds a 50 per cent. reduction in the oxygen absorbed was actually observed; at Leicester 36 to 60 per cent.; and at Birmingham 29 per cent. In the Hamburg experimental works the oxygen absorbed was reduced on an average by about 33 per cent. The albuminoid ammonia showed a reduction at Exeter of 38 to 54 per cent.; at Leicester 50 per cent.; at Birmingham 36 per cent.; and in the Hamburg septic tank about 23 per cent. At Hamburg the organic nitrogen was reduced about 37 per cent. and the organic carbon *about 40 per* cent. by septic treatment. From the above we may safely say that, in general, septic treatment reduces the dissolved organic matter in sewage by an amount which is at least as great as can be removed by chemical precipitation under the most favourable circumstances. On the other hand, the effluents from septic tanks yield larger quantities of the decomposition products of organic matter than are contained in the sewage. At Hamburg, for example, the increase in the free ammonia was on the average 13·5 per cent.; at Manchester 15·9 per cent.; at Birmingham 22·4 per cent.; at Exeter 36·1 per cent.; at Lille 26 per cent.; and at Leeds more than 100 per cent. In addition to the increased quantities of free ammonia, the effluents from septic tanks contain fairly large amounts of sulphuretted hydrogen. As to the actual amounts, few data have been published. At Hamburg amounts up to 1·5 parts per 100,000 have been observed. This gas is the cause of the offensive smell of septic tank effluents, which is especially noticeable when these are agitated, as is the case when they are distributed on biological filters. Experiments are now in progress with the object of fixing the sulphuretted hydrogen by passing the sewage through a layer of iron shavings before it leaves the septic tank. Such experiments have been carried out for months, and have yielded very satisfactory results during the whole period. It does not seem advisable to attempt to fix the sulphuretted hydrogen by adding iron salts to the sewage, for the fine flocculent sulphide of iron thus formed would either clog up the biological filters or pass through and give the effluent a blackish colour.

Septic Treatment as an Aid to Biological Filtration.—The question as to whether septic treatment aids the biological after-treatment must, after what has been said above, be answered by saying that it certainly reduces the amount of solid matter reaching the biological filters. Not only is the greater part of the suspended matter retained in the septic tank, but also a not inconsiderable proportion of the dissolved solids. This certainly goes a long way towards preventing the biological filters from sludging up. The weathering of the filtering material is also undoubtedly diminished by first septicising the sewage. It is, however, another question whether septic treatment so alters the organic matter in the sewage that its purification is rendered easier, or, as some authors maintain, first made possible.

The refuse from sugar factories, breweries, and similar works, which contains large amounts of carbohydrates and hence becomes acid when subjected to septic action, is undoubtedly more difficult to purify by biological methods when in a septic condition than when fresh. This fact, upon which I have insisted for a number of years, has lately been confirmed by other investigators.

But domestic and town sewage which does not become acid when allowed to become septic is also easier to treat biologically when fresh than when septic. At Hamburg, contact beds could be filled six times a day with fresh sewage without yielding an unsatisfactory effluent, whereas they would only take septic sewage twice a day.

The contrary opinions of English authors may be ascribed to the fact that they have compared fresh sewage, containing the whole of its suspended matter, with septic tank effluent, containing very little suspended matter. Under such circumstances it is only to be expected that filters will clog up sooner with fresh sewage than with septicised sewage. At Leeds, as soon as settled sewage was used, the results obtained were the same as those at Hamburg, *i.e.* in favour of dealing with fresh sewage. At Sutton, also, better results are said to have been produced by biological treatment after the suspended matter had been removed from the fresh sewage.

I am unable to advance any theoretical considerations which would support the opinions of various eminent English chemists that a septic sewage is more amenable to biological treatment than fresh sewage. The septic process changes the character of the dissolved organic solids in the sewage in such a way that their powers of absorbing and of being absorbed are undoubtedly diminished. Instead of the easily decomposable bodies present in fresh sewage, there are deposited on the surface of the filtering material, bodies which are with difficulty decomposable, and which therefore accelerate the clogging of the filter and disturb the absorptive processes which should take place.

Nitrification.—The widespread idea that nitrification, *i.e.* the conversion of nitrogen into nitric acid, is the only or the main function of biological treatment, seems to have led many astray. It has also been wrongly assumed that nitrification can only take place after the organic nitrogen has been mineralised, *i.e.* converted into ammonia. These mistaken ideas seem to me to form the only theoretical foundation for all the declarations in favour of septic action. Nitrifying organisms exist, however, which do not nitrify ammonia, but only organic nitrogen. Experiments, which I have had carried out with such organisms, have shown that they oxidise the nitrogen much more rapidly than the well-known nitrifying bacteria of Winogradsky. Besides these organisms, I am convinced, as I stated some years ago, that other oxidising micro-organisms play a very important part in biological purification. The above facts, then, counteract the advantages which the action of septic treatment may have in preparing the dissolved organic matters for a further biological treatment.

Moreover, nitrification is not such an important factor as has generally been supposed. It has been brought into prominence because it has been assumed that the nuisances caused by sewage were due to nitrogenous organic matter. I am prepared to admit that mineralisation and oxidation of the organic nitrogen are to be regarded as a most favourable sign of sufficient purification; but, if we leave out of consideration the question of utilising the purified effluent, I am not prepared to ascribe to nitrification much further importance. Other processes of decomposition and oxidation appear to me to be more important, chief among which is the mineralisation of the organic sulphur. It is the sulphur and not the nitrogen which *is the* cause of the nuisance arising from the decomposition of nitrogenous organic matter; it is the sulphur which forms the foul-smelling sulphuretted hydrogen, which is strongly poisonous to fish-life. The ammonia derived from the organic nitrogen can scarcely be smelled in putrefying sewage, and this fact scarcely seems to have been noted in the literature dealing with sewage.

As a rule, the sulphur escapes from the septic tank either in a gaseous form or as sulphide of iron in the effluent. The gaseous sulphuretted hydrogen escapes into the air as soon as the sewage is agitated by being spread out in contact with the air or by being sprayed from jets. The nuisance thus caused will probably have to be prevented by the adoption of some such precaution as was mentioned above. If the effluent from the septic tank is not agitated, but flows quietly, the sulphuretted hydrogen may be conveyed into the biological filters and there absorbed. Sulphide of iron is present in septic tank effluents, chiefly in very fine particles which cannot always be retained by the filters. It is, however, retained either by irrigation or land filtration. Added to the difficulty of preventing the escape of sulphuretted hydrogen and sulphide of iron is the fact that sulphide of iron is not so easily oxidised as organic sulphur.

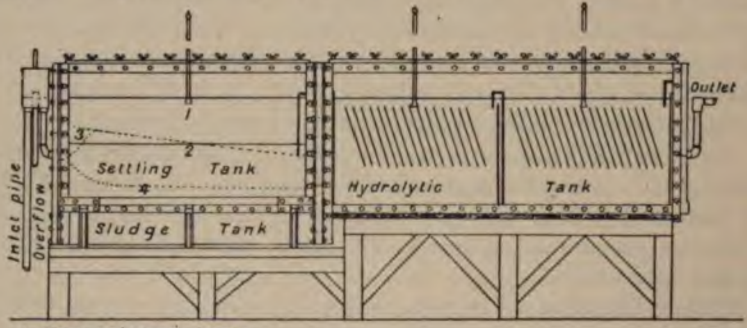
The oxidation of organic carbon also appears to be more easily accomplished when all the processes are aerobic than when anaerobic processes are introduced. This has been observed in the extended experiments which have been carried out at Hamburg, and the subject will be referred to later.

Sludge Digestion.—From the above considerations, in spite of the favourable results which have been reported with regard to the separation of suspended matters and the diminution of the dissolved organic matters, I must maintain that fresh sewage is more amenable to biological purification than septicised sewage. By this I do not wish to express any dogmatic judgment on the septic process. In forming an opinion, as we have seen and shall see later, a whole series of other questions must be considered, and it is necessary to judge each case on its merits. The first considerations should be with regard to the digestion of the sludge, its conversion into a less offensive product, and the decreased difficulty with which it may be stored for long periods.

The questions relating to sludge digestion are much more difficult than those above dealt with, relating to the decomposition of the dissolved solids. When the septic process became prominent, the sludge digestion was estimated at 70, 80, or even 90 per cent. of the total sludge. Later results have been published as follows:—Hampton, 58 per cent.; Glasgow, 50 per cent.; Huddersfield, 40 per cent.; Accrington, 35 per cent.; Sheffield, 30 per cent.; Leeds, 20 to 60 per cent.; Birmingham, 25 per cent., and quite recently 10 per cent.; and Manchester, 26 per cent.

It is to be expected that these figures will vary in the different towns, since the character of the sewage and its treatment before entering the septic tank are variable. The sewage of one town naturally contains more undecomposable solids, such as road detritus, than that of another; and some towns pass the sewage through detritus tanks and screens, whilst in others these processes are omitted. The amount of suspended matter escaping with the effluent from the septic tank also varies according to the construction and working of the septic tank—a fact which was little considered a few years ago.

At Manchester, for example, the septic tank effluent contained 19·3 parts per 100,000 of suspended matter; at Sheffield 15·7; at Oldham 14·3; at Accrington 17·8; at Leeds 12·9 with a twelve-hour flow, and 11·4 with a twenty-four hour flow through the tank; at Birmingham 24·4; and at Burnley 13·0 parts per 100,000, with an eight-hour flow through the tank. For comparison, the suspended matter remaining in sewage after chemical precipitation processes may be given. At London it was 9·0 parts per 100,000, at Manchester 6·0, at Leeds 14·0, at Salford 3·0 to 4·0, and at Birmingham 16·3.



1. Clear quiescent layer.
2. Turbid layer.
3. Path of lighter liquid
4. Path of heavier liquid.

FIG. 66.—Travis' Hydrolytic Tank Model.

Martin is of the opinion that a proper application of the latest experience would lead to better results with the septic process. At Barrhead he succeeded in reducing the suspended matter in the effluent from the septic tank to 8·0 parts per 100,000. This agrees with the result obtained at the Hamburg Experimental Station, 8·59 as an average for the years 1901 to 1904.

Hydrolytic Tank.—At this point a short description may be given of a method which has been worked out by W. O. Travis at Hampton. His object is to separate the putrescible sludge from the rest of the sewage as early as possible, and to allow it to become septic after separation. The principle of his method will be best understood from fig. 66. The sewage first enters a settling tank, and the specifically lighter components rise upwards (3) into the quiescent portion of clarified sewage (1). The specifically heavier constituents of the sewage sink to the bottom of the tank (4) into the turbid *liquid* portion of the sewage (2). The sludge falls into the sludge tank underneath the settling tank. From the upper clarified layer in the settling tank the sewage passes into the "hydrolytic tank," which contains a large number of plates. In the model depicted in fig. 66 a large number of parallel glass plates, placed slightly obliquely, were used. In passing between these plates the solids causing the liquid to be turbid, and which Travis regards as colloids, are deposited on the plates; as soon as this deposit attains a certain weight and thickness it slides off the plate to the bottom of the tank. According to Travis, these solids are no longer capable of active fermentation, and hence they remain in the tank without disturbing the process. The sewage then enters the second compartment of the hydrolytic tank, where the remaining solids are retained in the same manner. The principle upon which Travis' process is based is a rational one. The carrying out of the process in practice, however, has proved to be very expensive, and it is a question whether the increased work accomplished by the apparatus, in separating undissolved solids, bears a proper ratio to the increased cost.

Suspended Matter in Septic Tank Effluents.—The amount of suspended matter in the effluents from septic tanks appears to vary, as already stated, with the period of the year. At Leeds, for instance, the average amount in spring was 12·7 parts per 100,000, in summer 15·6, and in winter 21·3. At Huddersfield also the amount in winter was greater than in summer. These variations are probably due partly to the previously mentioned reactions taking place in the scum and partly to variations of wind and rain. Covered septic tanks are, of course, sheltered from the influence of the latter factors, and their influence in open septic tanks may be considerably diminished by the introduction of scum boards at short distances apart. The suspended matters in the effluent during the second and later years of working are usually higher than during the first year, and this is probably chiefly due to the accumulation of sludge in the septic tank.

All these factors make it very difficult to form even an approximate estimate of the amount of sludge digested in septic tanks, even from the results of working on a large scale. It may, however, be stated that, as a rule, one-third to one-fourth of the total suspended matter in the sewage reaching the septic tank leaves the tank with the effluent.

An estimate of sludge digestion is also complicated by the fact that the sludge alters in character in the septic tank, becoming more concentrated. Fresh sludge usually contains about 90 per cent. of moisture, whilst sludge which has been in the tank some time may contain as little as 80 per cent. The dry residue in the latter case amounts to 20 per cent., as against 10 per cent. in fresh sludge. Each cubic yard of septic concentrated sludge contains, therefore, as much solid matter as two cubic yards of fresh sludge.

From the above it will be seen that 25 to 30 per cent. of the so-called sludge digestion has been shown to be due to sludge deposition, and a still larger percentage is accounted for by the more concentrated nature of the sludge. The effect of such facts as these has been to make some authors so sceptical as to deny the existence of sludge digestion, or to assign a very small value to it, *e.g.* Dziergowsky gives 9 per cent. Such conclusions are, however, beyond the mark, and serve to show that the problem can hardly be solved by the results of operations on a large scale, but only by means of specially designed experiments.

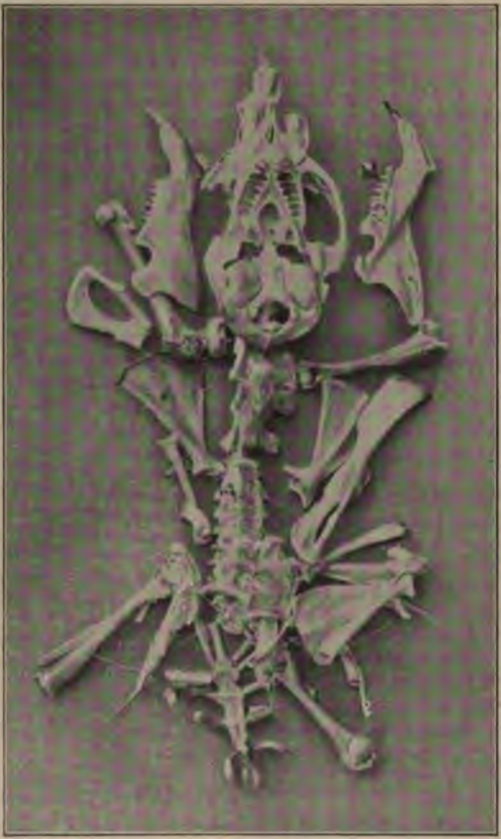


FIG. 67.—Remains of a Guinea-pig after three weeks in Septic Tank.

Solubility of Organic Substances.—The author has investigated the subject by suspending in septic tanks a large number of solid organic substances, such as cooked vegetables, cabbages, turnips, potatoes, peas, beans, bread, various forms of cellulose, flesh in the form of the dead bodies of animals, skinned and unskinned, various kinds of fat, bones, cartilage, etc., and has shown that many of these substances are almost completely dissolved in from three to four weeks. They first presented a swollen appearance, and increased in weight. The turnips had holes on the surface, which gradually became deeper. The edges of the cabbage leaves looked as though they had been bitten, and similar signs of decomposition were visible in the case of the other substances. Of the skinned animals, the skeleton alone remained after a short time; with the unskinned animals the process lasted rather longer. At this stage I will only point out that the experiments were so arranged that no portion of the substances could be washed away; their disappearance was therefore due to solution and gasification. The result of such a decomposition is shown in fig. 67. The skinned body of a guinea-pig was allowed to remain in a septic tank for three weeks, *when the clean white* bones, shown in the photograph, alone remained.

Further experiments have been carried out by Favre at the Hamburg Institute with proteins, albuminoids, fats, carbohydrates, etc., and it was found that the protein substances and albuminoids are the most easily decomposed, whilst fats are the most resistant, decomposition only taking place on the surface into fatty acids and glycerol. Carbohydrates are readily decomposed in the septic tank; cellulose also appears to be decomposed, but cork remains unaltered.

During the solution process the quantity of dissolved organic matter in the surrounding liquid at first increases; it is, however, very quickly further decomposed. The process takes place much quicker at first in a tank of twelve-hours' capacity than in one of two-hours' capacity, but very much quicker than in a septic tank in which the sewage is stagnant; hence, septic tanks should not be made too large, and they should contain no "dead" spaces, where the sewage may collect and become stagnant. The process takes place almost as quickly in fresh sewage as in septic. In pure water the above objects remained almost unattacked during a period in which they completely disappeared in either fresh or septic sewage, provided that the sewage was renewed from time to time.

In view of such observations, the opinion that the organic portion of the sediment in septic tanks is not decomposed, *i.e.* resolved either into a liquid or gaseous state, becomes untenable.

Objects suspended in the sludge itself are decomposed almost as quickly as those suspended in the supernatant liquid. I have formed the impression that the forces causing the solution process are developed within the organic substances, *i.e.* within the turnips, potatoes, dead bodies, etc. The process seems to be favoured by not allowing the sludge in the septic tank to occupy a large proportion of the capacity. I am at present attempting to solve these and similar problems by carrying out specially designed experiments, a description of which would occupy too much space here. Without such experiments it is impossible to make much progress in the problem of sludge digestion.

The reactions taking place during sludge digestion have hitherto been assumed to be due to the action of bacteria, but the assumption has been made without experimental foundation. Some years ago, as a result of preliminary experiments, I expressed the opinion that enzymes play a considerable part in these reactions. Further experiments have shown that diastatic and proteolytic enzymes occur in the contents of septic tanks in sufficient quantity to explain the liquefaction processes. The body of a guinea-pig, which had undergone decomposition in a septic tank, contained only proteolytic enzymes, but in considerable amount; a turnip, under similar conditions, contained diastatic enzymes; in either case, therefore, just the enzymes which were specially able to liquefy the substance in question. Similar results were obtained in the cases of the other substances examined. The enzymes are washed out of the substances in question, and are dispersed throughout the contents of the tank. Their nature and amount vary with the character and stage of decomposition of the sludge in the septic tank. It has also been shown that the enzymes isolated from septic tanks are capable of producing decomposition even in the absence of bacteria, but not so rapidly as when bacteria are present. I believe that further explanation of septic action is only to be obtained from the results of such experiments, and I have accordingly instituted a whole series with this object in view.

A considerable amount of organic matter escapes in a gaseous form, after decomposition in the septic tank. A few cubic centimetres of septic sludge, if placed in a vessel filled with water, soon give rise to the production of litres of gas. Septic tank gases have been analysed by various observers with very varying results. Methane has been found by some observers in quantities rather less than 20 per cent., by others up to 80 per cent.; hydrogen has been reported absent by some and present to the extent of 36 per cent. by others; carbon dioxide from $\frac{1}{2}$ to 40 per cent. This simply serves to accentuate the fact that the methods of research as yet adopted cannot yield satisfactory results. The objects above named, if left to undergo septic decomposition, yield at first gases which consist mainly of carbon dioxide and hydrogen, indicating that the carbohydrates are first decomposed. The simultaneous formation of lactic, acetic, and formic acids gives an acid reaction which changes to alkaline as the formation of ammonia and other basic decomposition products increases. The formation of hydrogen next decreases, and nitrogen and methane are formed in larger quantities. The above must suffice at this stage as a possible explanation of the discrepant results which have been obtained with regard to gas formation.

The opinion has often been expressed that the main function of the septic tank lies in the decomposition of cellulose. This opinion also needs correction, as I intend to show later. Sedgwick rightly draws attention to the fact that the portion of wooden stakes just above the soil rots much more rapidly than the buried portion. I believe that the action of aerobic moulds in decomposing cellulose has not received sufficient attention. Our experiments on the action of enzymes have also a bearing on the decomposition of cellulose. They indicate that nature supplies the necessary bacteria just where they are required to decompose putrescible matter, and at the same time supplies enzymes which are capable of aiding the action of the bacteria.

Removal of Sludge.—From the above we must not only conclude that the value of the sludge digestion phenomena should not be underestimated, but also that an explanation is offered why it is not necessary to allow sewage to remain in septic tanks for forty-eight hours or even longer, as was at first supposed, when the action of bacteria alone was considered. Under certain circumstances a short period, two to four hours, in the septic tank is sufficient to produce the same result as a much longer period. Originally the English Local Government Board required septic tanks to be designed for a flow equal to one and a half times the daily dry weather flow of sewage. Later, this requirement was altered to one and a quarter times the daily dry weather flow.

Septic tanks must certainly be constructed so large that sudden strong currents are avoided in the tanks. Small works are especially liable to this danger, with the result that the sludge is stirred up. The surface of the sewage in the tanks should also never be allowed to sink below a certain level. A sinking of the water level reduces the pressure on the sediment, which contains large quantities of septic gases, with the result that large quantities of solids suddenly rise and are washed out of the tank.

The sediment, which is partly solid, but chiefly of a slimy nature, is converted gradually by the processes which take place in the septic tank into a crumbly product, which does not possess the same affinity for water as fresh sludge. It is more easily drained; and when allowed to stand, exposed to the air, it is quickly converted into an inoffensiye earthy substance, possessing an odour of garden mould.

In large towns, where the question of sludge disposal is one of considerable difficulty and expense, it is only to be expected that the consequences of the above changes would admit of statistical expression. At Manchester, since the introduction of the septic process, upwards of 100,000 tons less of sludge are annually conveyed to sea than during the period when chemical precipitation was in use. This means a considerable saving of expense. At Birmingham, since the adoption of septic treatment, the number of workmen, continually employed on sludge disposal, has been reduced from twenty-six to six, and the annual saving effected by not using chemicals is about £4000; the sludge from the septic tanks can also be used for raising waste land, a use to which the sludge previously obtained could not be put.

For small towns, institutions, and private houses, one great advantage of the septic tank lies in the fact that the sludge can be left in the tanks for months or even years and removed only according to agricultural requirements. The vicinity of such works can thus be free from obnoxious sludge tips.

Open and Covered Septic Tanks.—The covering of septic tanks was supposed to be a guard against loss of heat, foul smells, and nuisances caused by insects, and, according to some authors, was necessary to ensure perfect anaerobic action. The utilisation of the septic tank gases was also intended, but has not been found economically possible. Perfect anaerobic action is also obtained in open septic tanks. In Great Britain and Germany no injurious effect has been traced to the loss of heat in open septic tanks, nor have nuisances been caused by odours or insects. In the immediate vicinity of dwelling-houses, covered septic tanks are to be preferred, but a covering of planks, with perhaps a little soil on the top, is generally sufficient.

Pathogenic Germs.—It is generally assumed that pathogenic germs are either injuriously affected or quickly destroyed in septic tanks, but the experiments which we were able to perform at Hamburg on this point did not convince us of the correctness of this view. Even non-resistant cholera-like vibrios persisted for several days in the septic tank. Septic action has, however, an important bearing on the destruction of infectious material. The slimy substances with which pathogenic bacteria are generally surrounded are liquefied, and the germs of infection are thus exposed to the action of disinfectants. This matter will be referred to in the chapter on *Disinfection.*

Scott-Moncrieff Tank.—For the sake of completeness, it should be mentioned that in 1891 Scott-Moncrieff constructed a so-called cultivation tank at Ashtead, and later at other places; but this will be dealt with in Chapter VIII. The whole arrangement is a septic tank filled with stones, the sewage entering at the bottom and leaving at the top. The action of a cultivation tank is, both qualitatively and quantitatively, the same as that of a septic tank.

Summary.—Summarising what has been said with regard to the advantages and disadvantages of septic treatment, as compared with other preliminary processes, I have come to the following conclusions:—

1. Septic treatment is not a complete sewage purification process, but only a preliminary treatment, at present adopted almost exclusively for biological after-purification, and in cases where disinfection has to be resorted to. It has, in a few cases, been adopted in connection with land treatment.
2. It relieves the works used for the final purification (*a*) by retaining the suspended matters, at least as efficiently as the sedimentation process, and almost as efficiently as chemical precipitation processes; and (*b*) by gasifying and mineralising about one-third to one-half of the dissolved organic matters contained in the crude sewage.
3. The amount of organic matter in the sludge retained in the tank is considerably diminished by the gasification and liquefaction (sludge digestion) as well as by the concentration caused by the septic action.
4. The sediment is converted by septic action into an almost inoffensive and easily drained substance. This has not been proved to be the case with the "biological plants for fæcal matter" (see p. 83).
5. The possibility of allowing the sludge to remain in the tanks for some months is a great advantage for some towns, institutions, and private houses.

On the other hand, septic treatment possesses the disadvantages that—

1. The tank effluents are always putrescent, and give rise to foul smells by the escape of gases when they are agitated. The most

important of these gases, sulphuretted hydrogen, may possibly be fixed before leaving the tank.

2. The biological after-treatment is usually more difficult with septic tank effluent than with fresh sewage.
3. The sulphuretted hydrogen formed in the tanks attacks the cement. It is stated that this may be avoided by a proper selection of the building material and by allowing the works to stand long enough before being brought into operation.
4. The accumulation of putrefying substances should, on general sanitary grounds, be prevented as much as possible. This is especially the case in the neighbourhood of dwelling-houses.

F. Precipitation.

Historical.—Proposals to purify sewage by the addition of chemical precipitants were made over a hundred years ago.

A patent was taken out in 1762 by de Boissieu for the purification of dirty water by a chemical process. Chemical methods, however, first assumed practical importance when the English authorities began to deal with the problems of town sewage and trade refuse, and no longer expressed themselves satisfied with the results produced by mismanaged sedimentation tanks. About the same time the question of separating the manurial constituents of sewage by chemical precipitation, already referred to in Chapter III., came to the fore. Speculation in these processes became rife, and hundreds of chemical precipitation processes were patented. A list of the precipitants which have been recommended and adopted from time to time would occupy too much space here. Descriptions and references to the literature on the subject are to be found in the well-known work of J. König, *Die Verunreinigung der Gewässer*.

The hopes of financial gain, which were raised in connection with these chemical precipitation processes, have not in any way been realised. An inquiry, instituted in 1894, showed that, of 234 towns which had adopted chemical processes, 204 had incurred expenditure without realising any income whatever; the remaining 30 had indeed obtained an income, but this was often only a few shillings which had been received for a few cartloads of sludge. In no case had a profit been realised.

With regard to the purification produced, precipitation processes have again and again given rise to disappointment. The splendid results obtained in laboratory experiments and specially-constructed experimental works led the authorities of English towns to persevere with experiments. Salford has at different times tried thirteen different methods, Birmingham seven, and almost every large English town can boast of a similar experience. About twenty years ago, following the example of England, a few German towns adopted chemical precipitation. In every case, however, the opinion of the English Commission, given in Chapter II., was confirmed, to the effect that chemical precipitation effected a satisfactory removal of the suspended matters, but yielded a putrescible effluent, which deposited solid matters in the bed of the stream; that the process was very expensive, and produced much larger quantities of sludge than were yielded by sedimentation. The sludge was practically unsaleable, and thus, owing to its putrescent character, the rapidly growing sludge-tips were a menace to the neighbourhood. The sludge question became a bugbear, which was partially overcome by the introduction of sludge presses, to which reference will be made later. Sludge presses were first used at Aylesbury, then at Merton, and Wimbledon (1884), and at the present day they are to be found at almost every sewage works. The presses convert the sludge into solid cakes, which are at least transportable. Hopes of utilising the sludge with the aid of sludge presses have not, however, been realised.

Partial Abandonment of Chemical Precipitation.—Almost twenty years ago, when artificial biological methods were first introduced, those who had been troubled for years with chemical precipitation began to breathe freely. They believed that the death knell of chemical methods was being tolled. At that time it was hoped that the artificial biological methods, to be described later, would be very much more economical than the chemical methods. Such expectations have not been fulfilled; but, in spite of this, the use of chemicals has gradually been given up, chiefly because the authorities ceased to be satisfied with the results produced, after it had been shown that artificial biological processes yielded better effluents.

As a complete method of sewage disposal, chemical precipitation is now only to be met with in a few towns, and these are mostly engaged with schemes for replacing it by biological processes. Such a position of affairs justifies a very short description of the processes of chemical precipitation, and I have chosen the processes at present in use at London, Glasgow, and Leipsic, as typical of those which may be considered feasible at the present day.

Precipitation of London Sewage.—The London sewage, about 200 million gallons daily, from a population of about four and a half millions, is conducted into nineteen tanks, thirteen of which are situated on the north bank of the Thames at Barking and six at Crossness, on the southern side of the river. Their total capacity is about forty-four million gallons. Originally they were worked intermittently, *i.e.* filled with sewage to which the chemical precipitants had been added, allowed to stand full for a time, and then emptied. In 1891, however, it was shown that better results could be produced by allowing the sewage to flow continuously through the tanks. The chemical precipitants in use are lime and copperas, six parts of the former and 1·4 parts of the latter being used at Barking per 100,000 parts of sewage. The volume of sludge which is deposited daily amounts to about 8000 cubic yards, and this is pumped into sludge tanks, from which it is discharged into tank steamers, after the top water has *been removed.* Six tank steamers, each of a capacity of 1300 cubic yards, are continually engaged in carrying the sludge to sea, a distance of 40 to 50 miles. The cost of transport of the sludge amounts to £50,000, and the cost of chemicals to £75,000 per annum. The total annual working cost is, roughly, £150,000. This process succeeds in removing 75 per cent. of the suspended matter from London sewage. This has been sufficient to improve the condition of the Thames, which, about twenty years ago, was becoming a menace to the shipping trade, to such an extent that at present no pollution of the lower reaches of the river is visible, and careful investigations during recent years have not revealed any sludge deposits in the bed of the river.

Precipitation at Glasgow.—Glasgow has at times hesitated whether to adopt biological or chemical treatment, but has finally decided in favour of the latter. The process is worked on the continuous principle, as in London. Lime and sulphate of alumina are used as precipitants, the quantities varying with the strength of the sewage. From published data, the amount of lime varies from 7·1 to 57·2 parts per 100,000 and the amount of sulphate of alumina from 3·6 to 28·6. The average cost of chemical treatment in Glasgow is 36 shillings per million gallons; and the amount of sludge obtained, containing 90 per cent. of moisture or slightly more, is 50 cubic yards per million gallons of sewage. From the London sewage 40 cubic yards of sludge are obtained from a million gallons of sewage, or 16 cubic feet per head of population per annum. The cost of treatment in London is about 40 shillings per million gallons, quite as much as at Glasgow, where the sludge is not carried out to sea, but pressed after the addition of a further quantity of lime. A small proportion of the pressed sludge, about 1000 or 1500 tons annually, is sold at a price of 20 to 25 shillings per ton.

Precipitation at Leipsic.—At Leipsic a salt of iron (a commercial basic sulphate) is used for precipitation, in amounts varying with the concentration of the sewage. On the average, 6·3 parts per 100,000 are employed. The cost of treatment is about 82 shillings per million gallons, or ninepence per head of population per annum. The amount of sludge produced is only about 24 cubic yards per million gallons of sewage, but it must be borne in mind that all fæcal matter does not reach the sewage works. The purification effected at Leipsic is higher than at either London or Glasgow. During 1904, Leipsic had to purify 4840 million gallons of sewage at a total cost of £20,000, and experiments have been commenced with the object of seeing whether the same result cannot be attained as cheaply by means of biological methods.

Precipitation Preliminary to Biological Purification.—In England, chemical precipitation is still being employed as a preliminary to biological purification. Bolton is using 9·8 parts of lime and 2·8 parts of iron alum; Salford 17 parts of lime, 8·5 parts of copperas, and about 12 parts of iron alum per 100,000 of sewage. Leeds has lately had a scheme prepared, in which it is intended to adopt chemical precipitation previous to biological filtration. The increased cost of chemical precipitation, compared with sedimentation or septic treatment, has been calculated to be more than counterbalanced by the saving effected on the after-treatment by biological methods. The nuisances caused by foul smells from septic tank effluents are also avoided. These points will be further dealt with in the next chapter.

Degener's lignite method is, strictly speaking, a precipitation process. It should also be classed with the methods by which it is attempted to attain a non-putrescible effluent, and hence will be dealt with in the next chapter.

By chemical precipitation, under the most favourable conditions, it is only possible to remove from 20 to 30 per cent. of the dissolved organic matter from sewage. Under certain circumstances, as to the volume and rapidity of flow of the river, etc., such as exist in London, a purification of this character is sufficient, and new projects are designed, not with a view to obtaining a higher percentage of purification, but in order to effect a saving of expense. Under less favourable circumstances, in which a non-putrescible effluent must be produced, and where a sludging up of the river bed is to be feared from the deposition of solids from the effluent after its discharge into the river, chemical precipitation methods cannot be considered as satisfactory.

CHAPTER VIII.

METHODS FOR THE REMOVAL OF PUTRESCIBILITY.

A. Surface Irrigation.

Historical.—Until about forty years ago, irrigation had only been adopted for the treatment of sewage in a few isolated instances. After the experts of the English Government had again and again unanimously characterised this process as the only satisfactory method of sewage treatment (see Chapter II.), the supervising authorities began to strongly urge its adoption. As an example of how this requirement was enforced, we may cite the case of the small town of Croydon, which is situated not far from London. At that time Croydon had rather less than 20,000 inhabitants; but in consequence of a large increase in the incidence of febrile disease, the town had adopted the water-carriage system of sewerage, and was discharging the whole of its sewage into a small stream, the Wandle. Nuisances arose in consequence of this, and the town was being continually subjected to legal actions, upon which over £10,000 had to be spent. Moreover, £25,000 had been spent in chemicals to deodorise the sewage, without, however, effectually abating the nuisances. The Court ordered the adoption of land treatment, but as soon as this was known the price of land rose enormously. In spite of this, however, persons were found willing to pay considerable sums for the town's sewage, and to enter into contracts for a period of years. All this happened at the time when Liebig, A. W. Hoffmann, and others were agitating so strongly in favour of irrigation, and had calculated the value of town sewage at no less than twelve or eighteen shillings per head per annum. It must be regarded as a consequence of this agitation that in 1876 no fewer than sixty-four English towns had adopted irrigation for the treatment of their sewage.

Clays not Suitable for Irrigation.—It must not be supposed that irrigation was carried out in the same manner as is the case at the present day on German irrigation farms. If a German town intends to adopt irrigation, it first appoints an expert to report whether suitable land is to be had within a reasonable distance of the town. In England, at that date and until within very recent times, the requirement for irrigation has been pressed, irrespective of where and how it could be carried out. Many towns could only obtain clayey land, such as is regarded in Germany as entirely useless for irrigation purposes. The case of Leicester will serve as an example of what occurred when towns were compelled to use clayey soil for irrigation purposes. The country around Leicester is undulating. The sewage was pumped into open channels at the highest point of the irrigation area, there allowed to overflow, and, following the inclination of the land, to spread over the surface. After each dose, the upper clay soil became so thoroughly soaked that it was necessary to wait about three months before the land could be farmed. Although it is generally regarded as inadvisable to drain clayey land, it was absolutely necessary to lay shallow drains in the Leicester land. The drains discharged a putrescible effluent, which was collected in cross-channels and conveyed on to a second field of grass land. If the effluent from the second field was still putrescible, it was distributed over a third series of plots, from which, as a rule, a non-putrescible effluent was discharged. This process, which is known as surface irrigation, appears to be much used in England, chiefly because the land in the neighbourhood of most of the towns is of a clayey nature, and not suitable for use in any other manner.

By means of the above method of irrigation, a satisfactory effluent can only be obtained by a series of successive treatments, and this is only possible if a very large area of land is available. It has been estimated that in this manner the sewage of twenty-five persons at most can be treated on one acre of land. If we think of the city of Leeds, which, with its population of 470,000, is situated in a district where the land is of a clayey nature and also very expensive, we see at once that irrigation under such circumstances is impossible.

In similar cases, *e.g.* at Draycott and Beverley, attempts have been made to render the soil suitable by artificial means. The clay has been dug out and replaced after being burnt, but good results have not been obtained in this manner. Other towns have mixed ashes or town's refuse with the clayey soil, in order to render it more permeable. In a few cases, *e.g.* at Eccles, satisfactory results have been obtained by such means.

Peaty Soil Unsuitable.—Peaty soil is as unsuitable as clay for irrigation purposes. Nevertheless, certain English towns have been forced to construct irrigation works on such land. The Royal Commission on Sewage Disposal, now sitting, has carried out very thorough investigations, and has come to the conclusion that peaty soil is entirely unsuitable for irrigation.

Distribution of Sewage.—In Germany it is not customary to regard irrigation as a process in which sewage is allowed either to evaporate or to flow over the surface of land, as in the cases of surface irrigation, above mentioned. It is regarded more as a filtration process, in which the sewage passes through the soil, and hence irrigation works in Germany have been constructed with this object in view. In England, so far as I have been able to gather from visits and from the evidence given before the Royal Commission, sewage is distributed on the land in much the same manner as has been described for Leicester. Where the land is more level it is necessary for a waterman, after opening hydrants or inlet channels, to remove obstacles out of the way of the sewage, so that it may be evenly distributed over the surface of the land and not allowed to collect in pools. Officials, whose reputation as irrigation experts stands very high in England, have informed me that this method of distribution is the most rational. Mawbey of Leicester calls it "the old orthodox method of irrigation." In Germany the land is usually so prepared that the distribution of the sewage is regulated by simply opening sluices, etc. The simplest method of distribution, which is somewhat similar to the above described primitive method, is that known as contour irrigation or ridge irrigation. On sloping ground, the sewage is first brought to the highest point of the land and allowed to flow over a small plot of land. It is then collected in a channel, from which it is evenly distributed over the next lower plot. If the land is very steep, it is necessary to construct a larger number of channels and dams, in order to retain the sewage longer and to effect more even distribution. If the land is more nearly level, ridge irrigation is adopted, an idea of which may be obtained from the illustrations (figs. 68, 69, and 70). In such cases the method adopted, which is very similar to that at Leicester, is as follows: The sewage from the sewers, or better from settling tanks, enters a distributing channel (A), which commands the whole of the area, and to which are connected at right angles smaller distributing channels (B). From the latter, which are blocked at the lower end, the sewage percolates through the soil, and, when they are full, overflows the surface of the plots and passes into the lower channels (C). These collecting channels communicate with a second distributing channel (D), from which the sewage passes along smaller distributing channels, as

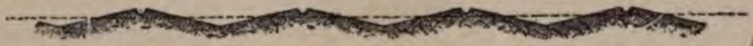


FIG. 68.—Ridge and Furrow Irrigation. Cross Section.

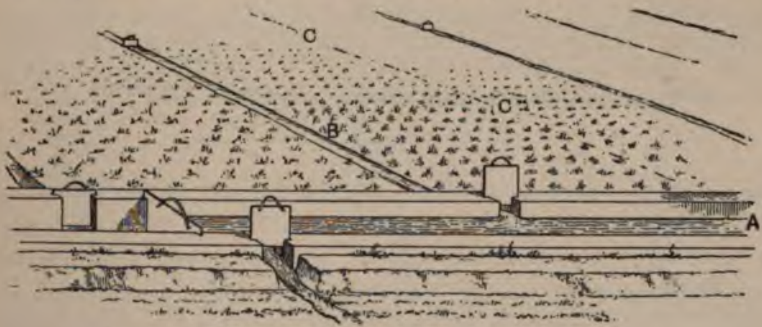


FIG. 69.—Ridge and Furrow Irrigation. Bird's Eye View.

before, and is irrigated over another series of plots (II., fig. 70), at a lower level. The effluent from these plots may then again be distributed over a third series. The single plots of land are generally constructed not more than about ten yards wide. Works, such as the above, are only specially suitable in cases where the land is so low-lying that it cannot be properly drained.

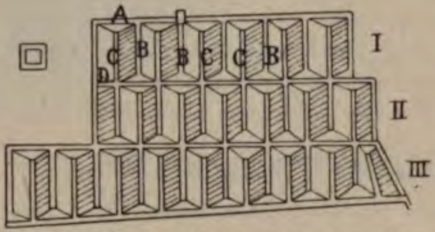


Fig. 70.—Ridge and Furrow Irrigation. Plan.

Whenever possible, in Germany, and apparently also in France (Paris), irrigation is carried out on the same principle as in market gardening. The sewage is not allowed to flow off from the surface of the land, but is compelled to filter through the soil. This method the Royal Commission on Sewage Disposal proposes to term land filtration, but it is not the same as Frankland's intermittent land filtration, which will be referred to later.

In this bed-irrigation the sewage is conveyed to the land along channels, as in fig. 69. The land, however, is not flooded, and the distributing channels are only partially filled, so that the sewage can only enter the beds from the side and beneath the surface (fig. 71). In this manner the stems and leaves of the plants, which are intended for human consumption, do not come into contact with the sewage, the moistening and manuring processes being restricted to the roots. The beds are usually constructed about a yard wide and not more than twenty to forty yards long, otherwise an even distribution of the sewage can only be obtained with difficulty. This process requires a large number of distributing channels and also paths, in order to attend to the beds, so that there is a considerable loss of available area.

Fig. 71.—Bed Irrigation. Cross Section.

Finally, we have the so-called flood method, in which a piece of land, usually from five to twenty-five acres in extent, is surrounded by earthen banks and flooded with sewage to a depth of ten to twenty inches. This method is only used in isolated cases as a winter method. Beds, before being arranged for bed-irrigation, and before the crops are in, are usually flooded with sewage. Bed-irrigation can only be used on level ground. Sloping ground may, however, be made available for this process by the construction of a series of terraces (fig. 72).

In 1882, Gerson adopted a method of distributing sewage at Hohenschönhausen, which had been recommended and adopted some decades previously *in England* (Fulham), but which had in the meantime been forgotten.

Gerson did not attempt any permanent adaptation of the irrigation area, but divided the land as near as possible into square sections, each about five to eight acres in area, and, with a special plough, surrounded these with furrows half a yard deep. The soil thus removed was used to surround the sections with banks half a yard high (fig. 73). The sewage was conducted to the irrigation area by means of a subterranean network of pipes, provided with valves at distances of every 200 yards. To these valves were attached short sections of pipe, the separate portions of which were fixed together by flexible connections and supported on fork-like arrangements. Two persons were required to work the apparatus, and the sewage was distributed either from holes in the pipes or by means of a hose-pipe. This method of distribution was abandoned in England, chiefly because it only appeared to be applicable in winter and for a short time in spring, if the crops were not to be drenched with the sewage.

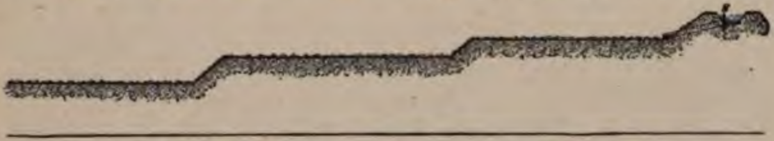


FIG. 72.—Irrigation on Terraces. Cross Section.

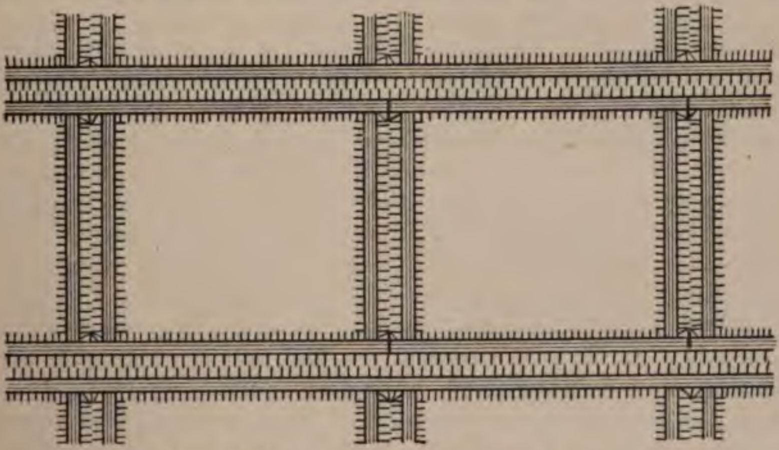


FIG. 73.—Gerson's System of Irrigation. Plan.

In 1897, A. Wulsch again took up this method of distribution at Eduardsfelde, near Posen. There, and also at Magdeburg, the surface of the land received no preparation. Valves were provided at various points, just as in Gerson's procedure, and to these were connected hose-pipes with which the sewage was spread on the land (fig. 74). Wulsch provided for the Municipal Agricultural Committee of Magdeburg an area of about 400 acres with subterranean iron pipes. The land received no special preparation, but was irrigated with sewage in the above described manner. The sewage, under a pressure of four atmospheres, was distributed by means of three movable lengths of cast-iron piping about three inches in diameter and each 400 to 600 yards long; also by means of hose-pipes twenty yards long and a little over two inches in diameter, provided with nozzles a little over an inch in size. The sewage was spread on the land ¼-inch to ½-inch deep. The preparation of the land only cost 64 shillings per acre, whereas for ordinary irrigation the cost was 440 shillings per acre.

$15.36

$105.60

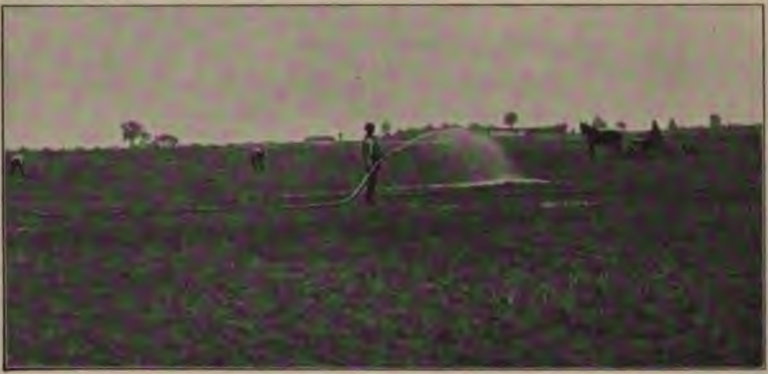


Fig. 74.—Wulsch's System of Spraying Sewage with Hose-pipe.

Although the cost of the system of Wulsch was only one-seventh of the usual cost of irrigation, the revenue was two to three times greater than is usually obtained, since the grass from the meadows which had been watered by means of the hose-pipes was in much greater demand. The director of the Magdeburg irrigation farm has stated, in a report, that irrigation by means of hose-pipes is the only possible way of increasing the produce from the meadows, without destroying the natural beauty of the district and without causing a nuisance to the public visiting the Herrenkrug.

Subsoil Irrigation.—Finally, the so-called subsoil irrigation should be mentioned. So far as is known, it was first used by Charpentier near Bordeaux, later by Henri Moule in England, and then, in 1875, by Col. Waring in North America, chiefly for small works, such as private houses, prisons, hotels, etc., and in one case for a village. According to Waring, who has introduced technical improvements into the method, the sewage must be freed as far as possible from suspended matter before entering the underground distributing drains. The latter consist of earthenware pipes, two to four inches in diameter, which, in sandy soil, are placed about a foot below the surface and in rows a yard or two apart. The pipes lie loosely in *half-pipes*, and at the joints are loosely covered with half-pipes (fig. 75), to

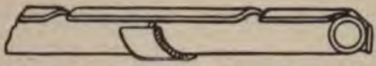


Fig. 75.—Subsoil Irrigation, Protected Drain.

prevent soil, roots, etc. from getting into them. The method has great advantages in cases where æsthetic reasons make it desirable to keep the sewage out of sight. The doubts which arise in connection with the system are entirely due to the danger of the pipes becoming blocked, a danger which would be very difficult to control. Waring states that some time ago, Oldcott had constructed over seventy works on this principle, and that they had all given every satisfaction. The cost for a private residence, under the expensive conditions prevailing in America, amounted to about £200.

Drainage.—In Germany only a few, and these small, irrigation farms are to be found which are not artificially drained. In England, according to the evidence given before the Royal Commission, drainage does not seem to be regarded as an absolute necessity for irrigation purposes. Various experts have indeed stated that drainage had proved to be harmful, but their remarks must certainly have been intended to apply only to land of a clayey nature. Often the holes which had to be dug in order to lay the drain pipes have been filled in with broken pieces of pipe or other similar large material, or even with gravel. This often allowed the sewage to find its way, not through the clayey soil, but direct into the drains without undergoing any purification. The sewage found its way direct into the underdrains all the easier because the distributing channels were also often placed directly over the underdrains instead of being placed at some distance. In winter, clayey soil often cracks to such depths that the sewage can reach the under drains unpurified. In Germany, permeable sandy soil is alone generally regarded as suitable for irrigation purposes, and in such cases artificial drainage of the land is advantageous, and especially so if the land is not naturally well-drained.

The above described method of bed-irrigation is, so far as I am aware, only carried out on artificially drained land. If the land is not at all or improperly drained, danger is to be feared in two directions. In the first place, no guarantee is provided that the sewage can percolate quickly enough through the soil. It may fill the pores of the soil, with the result that the oxygen in the air cannot enter. The organic matter in the sewage is then not oxidised or mineralised, and the effluent passes away in a putrescible state. The second danger, which is not only theoretically possible, but which has already been the cause of serious consequences, lies in the fact that the effluent cannot reach the stream into which it is intended to be discharged. It sinks into the ground until it reaches impermeable strata, along which it flows and finally collects, it may be at some considerable distance from the irrigation plots, causing land to be waterlogged. If the waterlogged land happens to be in a town, the district may be rendered almost or quite uninhabitable. The damage thus caused may be very considerable; and hence, before constructing irrigation works, it is necessary to institute very thorough investigations to see if a proper discharge of the effluent can be effected.

Drainage is usually carried out in the same manner as for agricultural purposes. The example of Sweden has been usually followed. Unglazed earthenware pipes, about two to three inches in diameter and about a foot long, are laid in the land about a yard or two below the surface, in rows eight to ten yards apart, the ends of the pipes being simply placed loosely together. The inclination of the pipes is about 1 in 200. These so-called suction drains are usually connected to collecting drains, constructed, as a rule, of glazed earthenware pipes not less than about two inches in diameter and well jointed together.

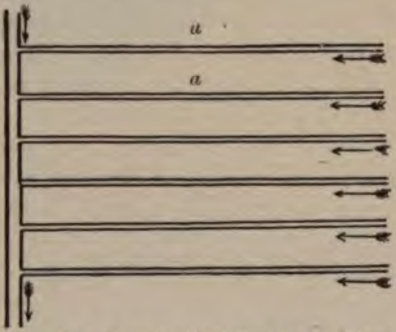


FIG. 76.—Longitudinal Drainage. Plan.

The arrangement of the drains depends upon the formation of the land. Three types of drainage are usually recognised; first, the so-called longitudinal drainage (fig. 76), in which the suction drains (*a*) are laid in the direction of greatest slope; secondly, cross-drainage, which is said to be more expensive, but more effective, and in which the suction drains are laid parallel to one another, but across the direction of flow of the subsoil water; and thirdly, diagonal drainage, in which the direction of the suction drains is inclined to that of the collecting drains, giving a herring-bone formation (fig. 77).

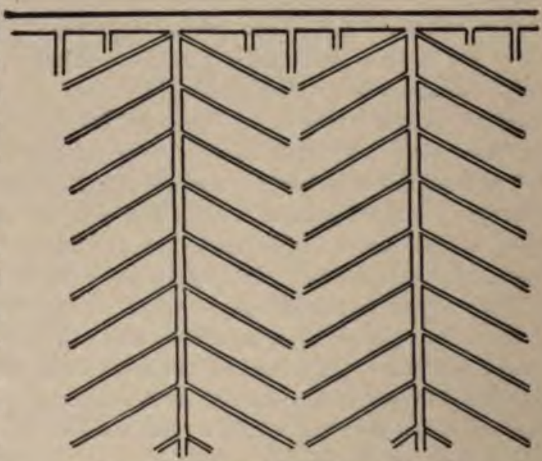


FIG. 77.—Diagonal Drainage. Plan.

Cost of Irrigation.—According to local conditions, the cost of drainage varies from about £8 to £30 per acre. Irrigation works, as may be judged from what has been said, are indeed very variable as regards cost. The total cost of preparing the land of the Berlin and Breslau farms amounted to about £40, and for Freiburg to about £80 per acre. The question of cost is more affected by the position of the land. In the neighbourhood of large towns the purchase price of the land is often very high. Berlin paid, on an average, £42 per acre, Breslau £30 to £32, and Freiburg £16 per acre. The acquired land generally increases in value with the lapse of time; and hence, in calculating the total cost of the works, it should not be necessary to provide a sinking fund for the land. Such a fund should, however, be provided for all works which are necessary to convey the sewage on to the land. If sewage has to be conveyed a considerable distance before reaching the land, and it is intended to reach the land by gravitation, very large sewers are often necessary, and these may be so expensive as to cost very little less than pumping. All such costs, together with interest and depreciation, must be taken into account in comparing the cost of irrigation with that of other methods. In some cases it is necessary to convey the sewage for miles; in Berlin, for example, over twelve miles, in order to reach the sewage works. In other cases the works may be constructed close to the town, and the cost of conveying the sewage will be naturally much less. It is apparent that a comparison, without taking into account all these facts, is not justifiable, yet such comparisons are frequently to be found among published records.

Utilisation of Sewage as Manure.—Attempts are often made to cover the expenses incurred in this manner by sowing crops on the irrigation areas. Irrigation is the only method of sewage treatment by which an income may be obtained. In this method attempts are made to utilise the manurial value of the constituents of the sewage; in all others, with the exception of methods of grease recovery and similar processes, which have as yet not been successful in obtaining an income sufficient to be reckoned with in dealing with the total cost of treating domestic sewage, the manurial constituents are sought to be destroyed. The manurial value of sewage was formerly calculated at eight shillings, or even as high as eighteen shillings, per head of population per annum. Relying on these calculations, private individuals undertook to pay considerable sums for domestic sewage. William Hope, for example, undertook, in 1864, to pay about £600 per annum for the sewage of 6000 to 7000 persons. He even considered buying the sewage of all London. In 1868 the Board of Health of Croydon actually let the sewage of Norwood for nearly four shillings per head per annum. In 1869 Aird declared his willingness to bear all the cost of conveying and preparation of land for treatment of the Danzig sewage in return for the free use of the same.

More recently the value of domestic sewage as a manure has been usually estimated at four to five shillings per head per annum. Hence, by a rational use of its domestic sewage, a town of 100,000 inhabitants might reasonably expect an income of nearly £25,000 per annum from its sewage. Even without taking into account the preparation of the land and the cost of conveying the sewage, but simply considering the working costs, such incomes have nowhere been obtained. No case is known which shows a profit from irrigation, when subjected to a strictly commercial investigation. Besides being due to the high cost of preparatory work on the land, the cost of conveying the sewage to the land and the working costs, this state of affairs is also due to the fact that the crops on one acre of land, even when grown on the most scientific principles and under most favourable conditions of soil, are only able to absorb the nitrogen from the sewage of twenty-five to thirty persons, the phosphoric acid from forty persons, and the potash from about eighty persons. Even if the land could be dosed with sewage regularly every day, a very large area would be required, and this would mean a tremendous expense to fully utilise the manurial constituents of the sewage. The crops, however, will not always bear irrigation, the process having to be stopped at certain seasons. Amongst agricultural chemists, opinions upon the important questions in this connection are very varied. A well-known German agricultural chemist has declared that irrigation areas should be sown with grass, because this will take the sewage even in winter; on the other hand, a well-known irrigation expert, whose practical results in this direction are everywhere recognised, tells me that grass should not be dosed with sewage in winter, for fear of injuring the roots. English irrigation experts seem to hold the latter view. From visits to English irrigation farms, I have gained the impression that grass and root crops (turnips, mangolds) are usually grown. On inquiring how this comes about, I have been informed that grass pays best, but that grass cannot be dosed in winter. Hence, besides grass, root crops are grown, because they only require the land for a few months, and it is allowed to lie fallow for the rest of the year, especially in winter, and in this condition will take much larger quantities of sewage. Also; whilst the root crops are growing, they will take much more sewage than grass.

Besides the above-named crops, various others are mentioned in the literature on the subject as being suitable for sewage farms. Willows are specially mentioned; these are said to grow luxuriantly, but, on account of the salts contained in the sewage, become brittle. Corn crops are recommended by some authors, and considered entirely unsuitable by others. Similar remarks apply to potatoes, celery, and sunflowers. At Freiburg, where the sewage farm may be regarded as a pattern of what sewage farms should be, a quarter of the land is planted with grass, a quarter with early corn crops, a quarter with turnips, maize, etc., and a quarter with late corn crops. It is not too much to say that such a farm must be under expert management, failing which it is far better, both from an economical and sanitary point of view, to grow crops on the simple principle which has been described as typical of English sewage farms.

Opposition of Economic and Sanitary Interests.—Inseparably connected with sewage irrigation is the fact that the economic and sanitary interests involved are diametrically opposed to one another. If the economic side of the question is to receive full justice, an agricultural chemical expert will be appointed to manage the farm, and he will be loath to apply sewage to the crops when they do not need it, for fear of spoiling *the harvest*. The sewage will therefore be allowed to escape untreated through the nearest storm overflow into the stream. If the sanitary side of the question is to receive proper attention, as is theoretically everywhere the case, but practically only in a few instances, the manager will be selected accordingly. He will regard it as his absolute duty to discharge the sewage to the stream only after it has been properly purified. There are undoubtedly eminent men who know how to combine these duties and to do justice to both economic and sanitary interests. Such men will be more easily found the larger the farm which they have to manage. For small works, however, it is more difficult, and in such cases the works might well be placed under the supervision of an expert.

It is an undoubted fact that better crops are produced from sewage-irrigated land than from other land. About fifty years ago some very interesting experiments in this direction were carried out at Rugby, where an area of twenty acres was divided into four plots. One quarter was not irrigated, the other three quarters were treated with various quantities of sewage, with the result that considerably better yields were obtained from the irrigated land. Since that date many scientifically highly interesting comparative experiments of a similar kind have been carried out, but it would lead us too far to discuss the results of these experiments in detail. It may, however, be mentioned that the cost of raising crops on sewage-irrigated land is considerably higher than when sewage is not used, and that the increased yield in the former case is largely counterbalanced by the increased cost. In Berlin, for example, one attendant is employed to irrigate each 75 acres, and a foreman for each fifteen attendants. In Freiburg one person has to attend to 250 acres, and in Breslau to nearly 500 acres.

Local conditions and the methods of cultivation exert a considerable influence on this problem. Some portions of the land will only take a dose of sewage about once a fortnight or even more seldom, whilst other portions can be dosed much oftener. At the above-mentioned places the works are carefully managed; and yet in one case three times as many and in another case six times as many workmen are employed as in a third case to attend to the same area. Numerous works are, however, sadly neglected, with the result that they present an appearance such as is shown in fig. 78. An official of one of the English supervising authorities stated in evidence before the Royal Commission that photographs of sewage farms which he had taken had been repeatedly regarded as seascapes. Such conditions are generally not entirely due to mismanagement, but are connected with the fact that the population has considerably increased, while the sewage works have not been enlarged or have been incapable of being enlarged. This factor of population may assume, under certain circumstances, considerable dimensions. The city of Birmingham, for example, is growing so rapidly that it would be necessary to increase the area under sewage irrigation by one acre per week. Such extension is not possible, on account of local conditions, and hence Birmingham has recently been compelled to adopt another method of sewage purification. Neglected or overworked land cannot, of course, yield satisfactory effluents.

Capacity of Irrigation Farms.—Generally speaking, land irrigation is still regarded as the best and safest method of purifying sewage. In favour of this opinion it has been argued that the soil only allows a certain volume of sewage to percolate, so that overworking is at once shown by the sewage remaining on the land and not by the escape of unpurified sewage. This argument, however, loses sight of the fact that when the land is covered with sewage for a period the escaping effluent is unsatisfactory. As soon as the oxygen, which has been collected in the soil, has been used up, and the absorptive powers of the soil have been exhausted, the sewage begins to flow away in a putrescible condition. It is true, however, that when the sewage is ponded on the land, the supervising authorities know that the works are not in order, and conclusions may be drawn from such ponding as to the inefficient state of the works. If there is no ponding, the inspector should convince himself that storm water overflows do not exist, through which the excess sewage is discharged to the stream without being treated on the land. It is generally admitted that such a state of affairs is far from uncommon. At one place I convinced myself that vertical drains, reaching up to the surface of the land, were placed for no other purpose than to take the sewage which would not pass through the soil. The attendant innocently informed me that this was the case. This action made an impression on me which was all the

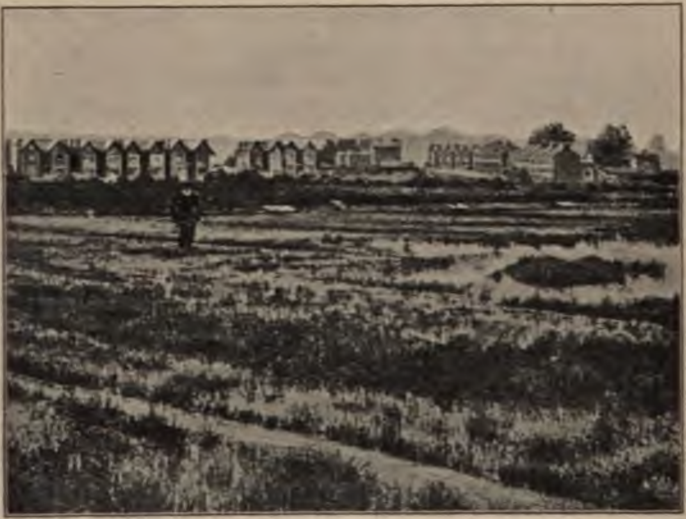


Fig. 78.—Flooded Irrigation Farm.

deeper because the results obtained at this place were being used as a basis in support of certain views on the quantitative capacity of soil to deal with sewage. Even apart from such intentional deception, it is very difficult to form a correct estimate of the capacity of irrigation farms. It has already been pointed out that, so far as the utilisation of the nitrogen is concerned, even under the most favourable circumstances, the sewage of not more than twenty-five to thirty persons should be treated on one acre of land. As a rule, sewage farms are worked at a much higher rate than this, seldom at a rate less than 150 to 250 persons to the acre. On the largest sewage farms of Germany, the rate varies from about 80 to 200 persons to the acre (Berlin 105, Breslau 187, Brunswick 88, and Steglitz 185). Until within very recent times the view has been held by agricultural chemists that if the land is worked at a rate in excess of the absorptive capacity of the crops the sewage will escape unpurified. This widespread idea arises from a confusion of the question of rational utilisation of the manurial constituents of sewage on the one hand, and the question of purification on the other hand. In the next section we shall see that land is able to efficiently purify sewage when it is not planted with crops. Hence a comparison could only be made with respect to the question as to whether a larger amount of manurial substances, such as nitric acid, is discharged when the farm is worked at a rate in excess of the powers of absorption of the crops. Theoretically the answer to this question is in the affirmative; but practically it is very difficult to decide, because of the difficulty in ascertaining whether the total volume of the sewage placed on the land is discharged, whether the effluent is mixed with subsoil or rain water, how much of the sewage is evaporated, and whether the samples of effluent correspond to the samples of sewage taken. The influence of such factors can scarcely be estimated with any degree of accuracy. Besides this, very few scientifically planned experiments have been carried out with sewage irrigation as compared with other methods, notably intermittent filtration and artificial biological methods.

The capacity of a sewage farm is determined by, first, the nature of the land; secondly, the manner in which the land is prepared for irrigation; thirdly, the climatic conditions; and, fourthly, the character of the sewage.

In very dry climates a considerable quantity of the sewage evaporates, and the volume of the sewage is not liable to sudden increase by reason of rainfall. The sewage can thus be brought on to a dry soil, which is very absorbent. This is not the case in Germany and England. The majority of the towns are sewered on the combined system; and thus on wet days the volume of sewage, with which the farm is expected to deal, is considerably increased. In England the authorities generally require the sewage to be treated on the land until a sixfold dilution is attained, that is, six times the dry weather flow must be treated on the land. On wet days the land is already soaked, and on that account is not able to deal with as much sewage as on dry days. With sandy soil this effect is not so great as with clayey soil.

In large towns the character of the sewage is usually not so altered by the presence of trade refuse, even in large quantities, as to render the purification of the sewage by irrigation impossible (see Chapter V). Hence the main factor in influencing the character of the sewage is the water consumption which, in almost all large towns, reaches 22 gallons per head per day, and usually exceeds this figure by a not inconsiderable amount.

The relatively large amount of salts present in sewage has an unfavourable influence on the crops. It has already been mentioned that willows have been rendered brittle from this cause, *e.g.* at Breslau, where the chlorine in the sewage is said to be 13·7 parts per 100,000, a figure which is less than those of Berlin (16·7), Birmingham (21·8), Hamburg (23·8 at present), or Wiesbaden (35·0).

The undissolved solids in sewage exert a considerable influence upon the capacity of irrigation farms. Grease is specially injurious. Schreiber has made some very valuable investigations on this subject at the Berlin sewage farms. He estimates the amount of grease in Berlin sewage as equivalent to 20 grammes per head per day, or for the whole of Berlin at 13,000 tons per annum. From these figures he calculates that each square yard of the land at the sewage farms receives about 0·5 gramme of grease per annum. The mud, which collects on the surface of the land, contained, according to Schreiber, 16 per cent. of grease and 0·1 per cent. is said to be sufficient to render even sandy soil impermeable. Hence the necessity is apparent of keeping the grease off the irrigation areas (see Chapter VII., C). Besides grease, other substances, such as finely felted fibrous material, render the soil impermeable, so that neither water nor atmospheric oxygen can enter, and thus the growth of the crops is interfered with. For these reasons, and also in order to increase the capacity of sewage farms which cannot be extended so as to keep pace with increasing population, it has been found necessary to remove suspended matters from sewage before distributing it on the land. At Dortmund the sewage is passed through the deep tanks remaining from earlier operations (see Chapter VII., D) before it reaches the land. In other German towns, so far as I am aware, little is done with the sewage as a preliminary to irrigation. In England, on the other hand, various towns submit the sewage to a preliminary septic treatment (Birmingham), others to chemical precipitation with lime, copperas, or sulphate of alumina. Most English towns are, however, like Birmingham abandoning chemical precipitation and adopting either septic treatment or artificial biological methods as preliminary to irrigation. Tatton, whose position as Chief Inspector of the Mersey and Irwell Joint Committee gave him exceptional opportunities of judging, estimated the value of this preliminary treatment very highly. On the most suitable soil Tatton estimates *that the* sewage of 100 persons can be dealt with per acre, but in conjunction with chemical precipitation the number would be 500, and in conjunction with artificial biological treatment he estimates that the sewage of 1000 persons could be dealt with on one acre of land. On clayey soil he considers it possible to deal with the sewage of 50 persons per acre without preliminary treatment, with that of 100 persons after chemical precipitation, and with that of 300 persons after artificial biological treatment.

I am convinced that the separation as completely as possible of all suspended matters, especially of the grease, should be recommended for all large sewage farms. Even in very small works, such as those of country residences, where it is not desirable to be continually removing the sludge, and for which, therefore, sedimentation or chemical precipitation is unsuitable, it will be advisable to adopt a preliminary septic treatment as soon as septic tanks can be so constructed and operated as not to give rise to any nuisance.

Even without the previous removal of suspended matter, some sewage farms have been in operation for a long time (see Chapter III.). Of the eight best English farms in operation at the present day, five have been in use for over thirty years without showing deterioration. Every farm, even the best, will at times get into such a condition that the soil is impermeable to water and air, owing to overworking—the surface of the soil becomes slimy and the pores are stopped up, with the result that the sewage is not sufficiently purified nor can the crops grow properly. In such cases the land is said to be "sewage sick." Its condition may be improved by ploughing and allowing it to lie fallow for a time.

It must, however, not be forgotten that the decomposition of the organic matters in sewage gives rise to a very stable, almost undecomposable substance, humus, which surrounds the particles of the soil and stops the pores. This action is far greater in intermittent filtration than in irrigation, since in the latter case less sewage is placed on the land, and the surface is oftener loosened and renewed by ploughing and harrowing and by being allowed to lie fallow.

It will have been noted that the results of irrigation, from a sanitary point of view, are influenced by many factors, some of which it is impossible to control, and yet, in spite of this, irrigation is still regarded as the best method of sewage purification. Its application as a method of raising crops is only possible, generally speaking, at the expense of the purification. It has, however, been generally recognised that profits cannot be obtained from sewage irrigation. Contrary opinions, which are held by imaginative individuals, but not supported by actual observations, are continually cropping up and being urged with the ardour of prophets. They may, however, reasonably be neglected here.

Sanitary Results.—From the sanitary standpoint, then, irrigation still enjoys the premier reputation. As regards the danger to health of the neighbourhood, which is theoretically possible, epidemiological observations have not given any practical cause for fear. The attack in this direction, which was made on the Berlin sewage farms in 1893, did not injure their reputation in any way. Statistics have been produced from which it might be inferred that sewage farms are suitable as resorts for invalids. Leaving such exaggerations aside, it may be stated, taking into account all the experience which has been gained, that the health of those employed on sewage farms and in their neighbourhood is not endangered by the presence of the sewage farms. I consider it unquestionable that, through carelessness in drinking drain water, etc., intestinal diseases may be and have been caused. It is also not to be denied that, under specially unfavourable weather conditions, sewage works may give rise to objectionable smells. Maclean Wilson, the Chief Inspector of the West Riding of Yorkshire Rivers Board, considers it possible that these odours may be the cause of indisposition to persons in delicate health, but he considers that they may be generally avoided by surrounding the sewage works with bushes. The planting of bushes is not only an æsthetic precaution, but also serves to lessen the depreciation of property in the neighbourhood of the sewage works.

The question of how the purifying action of land upon the sewage is to be explained is an important one. It has already been mentioned that the reputation of sewage farms rests upon the assumption that the soil will not take more sewage than it can deal with. The weaknesses of this assumption have already been demonstrated. The chief weakness is that the sewage which will not pass through the soil is discharged without further treatment. In this way a condition of affairs is produced which is decidedly worse than is the case with artificial sewage purification works, which are generally so constructed that it is impossible to discharge unpurified sewage to the stream except through storm overflows. The chief advantage over other purification methods, which is ascribed to land treatment, viz., the removal of pathogenic germs from the sewage, loses its importance when we consider the irregularities in operating sewage farms and the above mentioned practice of discharging untreated sewage. It is, however, an undoubted fact that under favourable local conditions, and with careful management, the bacterial content of the sewage is considerably reduced by land treatment. The thorough investigations of Schottelius and his pupils have shown that the number of bacteria in the Freiburg sewage is reduced from 790,600 to 6700 per cubic centimetre, *i.e.* on an average by 99·2 per cent. The careful investigations of Beckurts and Blasius at Brunswick have shown that there the number is reduced from nearly two millions to 5500 per cubic centimetre, *i.e.* by 99·7 per cent. Similar results are reported from Paris. An examination of the sewage of Berlin (Sputendorf) by Salkowski yielded 12¾ million developable bacteria per cubic centimetre; the effluent from the sewage farm only contained 3570 per cubic centimetre, equivalent to a reduction of 99·9 per cent.

These investigations do not, of course, take into account the sewage which escapes untreated, nor the dilution of the effluent with subsoil water, etc. They show, nevertheless, that a large proportion of the sewage bacteria are retained by the land, and thus kept out of the rivers; and those who have learned that in practice perfection is never or hardly ever attained will no more consider this action as useless on account of its imperfection than they do the action of drinking water filters, which are known not to retain all the bacteria of river water. In the other direction it should never be forgotten that the best effluents from a sewage farm are never suitable for drinking purposes. Even though the number of bacteria in sewage is very considerably reduced by efficient land treatment, the effluents still retain the bacteriological character of the sewage. This is evident from my own observations, as well as from those of Houston, undertaken for the Royal Commission on Sewage Disposal. Even the best effluents from sewage farms contain coli bacilli in considerable numbers, and it must therefore be assumed that pathogenic germs, such as typhoid bacilli, can pass through the soil and reach the streams uninjured.

Physical and Chemical Results.—Also from the physical and chemical standpoint the action of irrigation farms seems to me at the present time to be somewhat exaggerated. I have had this impression for some years, and it has lately been strengthened by visiting various English sewage farms, which have been characterised by the Royal Commission as the best in the country. If one regards not only the trickle in the smaller drains, but also the flow in the main effluent channel, one sees an almost clear and colourless product. It contains, however, a considerable number of lumps, the size of a hand or even larger, of characteristic sewage organisms. At Birmingham it has been necessary to retain these growths by placing screens in the effluent channel. Hence, in comparing land treatment with artificial biological processes, a perfectly clear effluent should not be regarded as the invariable result of land treatment, nor should the flocculent matters which separate from the effluents of artificial filters be regarded as characteristic of these alone. I only mention these growths, because I think that comparisons are usually made unjustly to the disadvantage of artificial biological methods; only in very exceptional cases do I consider that they have an æsthetic or sanitary importance or affect fish life.

Judged by the ordinary chemical standards, the effluents from well-managed sewage farms are highly satisfactory. They do contain more chlorides than are found in most streams, and the same remark applies to other inorganic substances which are of trivial hygienic importance. The oxygen absorbed is usually reduced by 80 or 90 per cent. (Freiburg, 77·2 per cent.; Brunswick, about 85 per cent.; Berlin, about 90 per cent; see Table). It is always difficult to estimate the influence of subsoil water, rainfall, and evaporation upon these factors.

Parts per 100,000.	Berlin.			Brunswick.			Freiburg.		
	Crude Sewage.	Effluent.	Decrease per cent.	Crude Sewage.	Effluent.	Decrease per cent.	Crude Sewage.	Effluent.	Decrease per cent.
Total solids	97·84	98·70	..	84·84	60·19	29·1	..	..	..
Loss on ignition	28·52	12·40	56·5	70·07	20·00	71·1	..	..	..
Oxygen absorbed (Kubel)	8·34	0·84	89·9	6·10	0·91	85·1	6·35	1·45	77·2
Chlorides (Cl)	28·38	23·27	10·1	14·60	12·94	11·4	4·00	3·40	15·0
Ammonia (NH_3) (free and saline and albuminoid)	9·95	0·23	97·7	14·32	0·41	97·1	..	..	..
Bacteria per c.c.	..	..	..	1,721,000	5591	99·7	790,600	6700	99·2
Nitrous and nitric acids	..	14·66	..	..	14·85	..	0·80	0·80	..

It may be stated that those effluents from well-managed farms, which have really passed through the soil, do not leave anything to be desired from a chemical point of view. On the other hand, as will have been inferred from what has been said, effluents are sometimes produced which differ little in appearance from sewage, and which are highly putrescible.

B. Land Filtration. (Frankland's Intermittent Filtration.)

Experiments at Ealing and Chorley.—It seems to have been known, ever since irrigation has been adopted for the treatment of sewage, that more sewage can trickle through and be purified by fallow land than by plots planted with crops. In spite of this, however, the conviction seemed to be general, that a successful and continuous purification of the sewage was only possible with the aid of higher plants. The belief prevailed that in fallow land the filth was only retained and not decomposed. Such an idea seems to afford an explanation of the fact that, during its systematic visitation of sewage purification works, the Rivers Pollution Commission of 1868 only came across two places where the purification of sewage was attempted without the aid of crops. These two places were Ealing and Chorley.

At Ealing the purification of the sewage had first been attempted with sand and gravel filters. These materials had then been replaced by burnt ballast and coal. The sewage was not conducted on to the surface of the filter, but underneath. At the time of the visit, and as a result of analytical investigations, the Commission came to the conclusion that no appreciable purification of the sewage was obtained by this process. Laboratory experiments which Sir E. Frankland carried out on the principle of upward filtration also showed no good result.

In June 1868 the Royal Commission visited the sewage purification works at Chorley. The town's sewage was conducted on to fallow land, which was roughly ploughed, but not planted with any crops. Here also the impression was obtained that no satisfactory purification was produced, *because the effluents* did not contain nitrates. The analytical results published by the Commission appear at first sight to show a considerable purification. The organic carbon in the sewage is reduced by 62·3 per cent., the organic nitrogen by 70·3 per cent., the ammonia by 68 per cent., and the total nitrogen by 68·8 per cent. The effluents were practically free from suspended matter. Since, however, the chlorides in the effluent were about 34·5 per cent. lower than in the sewage, it must be assumed either that the samples of effluent and crude sewage did not correspond or that a considerable dilution with subsoil water was taking place.

Frankland's Experiments. — In conjunction with these visits, Sir Edward Frankland carried out laboratory experiments which have formed the basis of the modern development of biological sewage purification. He used glass cylinders, 6 feet high and about 10 inches wide, open at the top and bottom, and these were placed in shallow earthenware troughs. A glass tube was inserted in the middle to serve for aeration purposes. A 3-inch layer of gravel was first placed in the cylinder and over this a 5-foot layer of the soil under investigation. If the soil was very coarse it was covered with a 1-inch layer of fine sand, to prevent coarser suspended solids entering the filter. For his investigations Frankland used: (1) a coarse porous gravel from the much cited Beddington irrigation meadows near Croydon; (2) sand from the red sandstone near Hambrook; (3) soil from the Barking irrigation farm; (4) a light yellowish-brown loamy marl from Dursley; and (5) peaty soil from Leyland.

These filters were dosed every morning and evening with London crude sewage. Filter 1 at the rate of about 3½ to nearly 15 gallons per cubic yard, filter 2 at the rate of 6 gallons per cubic yard, filter 3 at the rate of about 3½ gallons per cubic yard, filter 4 at the rate of 4 to nearly 13 gallons per cubic yard, and filter 5 at the rate of about 4 gallons per cubic yard. The experiments were carried on for about four months, and the results produced were very satisfactory. The effluent was clear and almost colourless and odourless, and contained a considerable quantity of nitrates. At the end of the experiments the samples of soil did not show any signs of becoming clogged, and the Commission came to the conclusion that with the best of the filters (No. 1) 44,000 gallons of sewage could be thoroughly purified on one acre, if the drains were laid at a depth of 6 feet. At this rate the purification should go on for all time without fear of stopping up the pores of the soil. Frankland considered the action as comparable with the action of the lungs in breathing. He considered that it would be sufficient to level the surface of the land and divide it into four equal plots, dosing these one after the other each for six hours with sewage, thus requiring only five acres of such land filters for a town of 10,000 inhabitants. Frankland and the Royal Commission of which he was a member, believed that various difficulties stood in the way of the general adoption of this method of intermittent filtration. These difficulties were: (1) That no pecuniary profit would accrue from the adoption of the process; (2) a fear that putrefactive decomposition would take place on the surface of the land and result in nuisance to the neighbourhood; and (3) a fear that it would be very difficult to obtain an even distribution of the sewage over the land on a large scale. The Commission, however, does not appear to have attached very great importance to these difficulties, for in their report, published in 1871, they express themselves very favourably concerning intermittent land filtration, and even go so far as to express the opinion that concentrated trade refuse may be purified in this way.

In 1877 Robinson and Mellis were able to cite thirty-eight towns which had attempted to purify their sewage by filtration, but, according to these authors, the results had been nowhere satisfactory. Irrespective of whether soil, gravel, coke, or other filtering material had been employed, the attempts had resulted in a complete stoppage of the pores of the filter and the formation of an impervious layer of undecomposed putrescent matter on the surface of the filter, causing a nuisance to the neighbourhood. They considered that intermittent filtration could only be adopted for very dilute sewage and then only after a preliminary chemical treatment. A closer examination of the details of these filtration experiments reveals the fact that, although the experiments were carried out in every conceivable manner, the rules laid down by Frankland were not adhered to in any one case. These rules seem to have been so soon forgotten, that, in 1880, Latham, one of the most experienced of English sewage experts, maintained that he had invented intermittent land filtration, following up the experiments of Schloesing and Müntz, which will be described later. Latham first erected an experimental filter at Croydon, and in 1883 he designed the land filters at Friern Barnet, which will be dealt with later.

Bailey Denton's Experiments and Operations.—Frankland had a true disciple in Bailey Denton, who, in 1871, shortly after the publication of Frankland's experiments, adopted intermittent filtration at Merthyr Tydvil, in order to get over a temporary difficulty. The sewage of this town had to receive a land treatment, but the preliminary details could not be carried out quickly enough. Hence, about 20 acres of very porous sandy soil covered with humus was underdrained at a depth of 6 feet, levelled and divided into four equal plots. Each plot was treated for six hours with the sewage of 25,000 persons, exactly as Frankland had prescribed. The amount of sewage treated was about 35,000 to 50,000 gallons per acre per day and on wet days twice this volume. The purification effected was very satisfactory; but the works were discontinued after five months, as the sewage farm, which had an area of about 300 acres, had been completed in the meantime.

Bailey Denton has constructed a large number of land filtration works in England and Scotland, nearly always as relief works in connection with irrigation farms. In 1896 he published a description of eight such typical works, in order to show that the process is suitable not only for schools and hospitals, but also for towns with populations varying from 1000 to 70,000. The reports and analyses accompanying the description show that the purification works leave nothing to be desired.

In general, however, Frankland's process was confused with sewage filtration experiments such as have been described above and which gradually brought filtration processes into discredit.

Experiments at Clichy.—In 1880 a small filter for laboratory experiments was constructed at Clichy, and worked on the intermittent principle for five years, producing very good results, and at the end of that time the sandy filtering material showed no signs of clogging. So far as I am aware, these experiments were not continued on a large scale.

Experiments at Lawrence.—Frankland's observations would doubtless have been gradually lost sight of, if the Massachusetts State Board of Health had not become interested in the subject. By an Act of 1886 this authority was entrusted with the supervision of all matters relating to river pollution, and granted powers to carry out experiments on sewage purification. With this object, an Experiment Station was erected at Lawrence, and in 1886 the Board compelled the small town of Medfield to construct sewage works on the lines of Frankland's system.

In its Nineteenth Annual Report (for the year 1887) the Board states that by the adoption of irrigation about 2500 gallons of sewage per day may be treated on an acre of land; that by intermittent filtration Frankland succeeded in treating 30,000 to 80,000 gallons per acre daily; and that at various works constructed on Frankland's system in England and on the Continent 35,000 to 90,000 gallons per acre per day have been efficiently purified. The report goes on to state that it is therefore possible to treat ten to twelve times as much sewage by this process as by irrigation, and that the Board must regard it as a duty to ascertain whether similar results can be produced under the climatic conditions of Massachusetts; that not only in the interests of the State of Massachusetts, but in the general interest, is it necessary to carry out careful experiments on the applicability of Frankland's process.

Dibdin has recently stated that the Massachusetts State Board of Health took up these experiments after the publication of a lecture delivered by him in 1887, in which he drew attention to the fact that the purification of sewage is only possible with the aid of micro-organisms. That this can scarcely be so is apparent from the Report of the State Board, which ends with September 1887, and in which important series of experiments are discussed, and, furthermore, from the fact that the Board had compelled the small town of Medfield to adopt Frankland's intermittent filtration during the year 1886.

If Frankland's experiments are to be regarded as the basis of modern biological methods of sewage treatment, they have really attained this position with the aid of the systematic and scientifically carried out experiments of the Massachusetts State Board of Health. This Board has not been content with solving the problem only so far as was necessary for Massachusetts conditions, but has extended its experiments so as to make them of general importance and applicability. In Massachusetts the soil is almost everywhere porous and sandy, but the State Board has not restricted itself to experiments with such soil; it has selected all kinds of filtering material, has aimed at finding that which is most suitable, and in other ways has aimed at increasing the efficiency of intermittent filtration. These experiments have really formed the basis of so-called artificial biological methods, with which we shall have to deal in the succeeding section.

At the Lawrence Experiment Station ten wooden tanks, of a depth of 6 feet and each $\frac{1}{200}$ of an acre in area, were let into the ground, and provided with effluent pipes leading to the buildings of the Experiment Station, where means were provided for carefully measuring the volume of effluent and for taking average samples. Into one of these tanks (Filter No. 1) a layer of very coarse mortar sand, 5 feet deep, was placed; into a second, very fine white sand; into a third, peat with a covering of earth; into a fourth, very fine river silt or sand; into others, garden soil, mixtures of sand and gravel, or loam, or clay and sand. The tanks were first partly filled with water and the various materials thrown in with a shovel. This method of forming the filters will have given rise to a certain gradation in the layers of the filter, which will not have been without influence on the experiments.

One of the tanks was used for the measurement of the rainfall and the evaporation.

At first the filters were dosed nine times a day. During the first six years the amount of sewage passing on to Filter No. 1 was gradually increased from 53,000 to 123,000 gallons per acre per day. The effluents contained on an average 6·25 parts of nitric acid per 100,000, and showed an average reduction of 87·5 per cent. on the oxygen absorbed figure. The number of bacteria was reduced from about $1\frac{1}{2}$ millions to 40,000 per c.c.

Filter No. 2, containing fine sand, purified during six years' working, an average quantity of 33,000 gallons of sewage per acre per day, reducing the oxygen absorbed figure by 95·2 per cent. The effluent contained, on an average, 6·13 parts of nitric acid per 100,000, and only 550 (sometimes even less than 100) bacteria per c.c.

The peat was almost impermeable for the sewage.

In 1891 a filter was constructed of gravel, about 1·4 mm. in size; and in the succeeding years this filter dealt with gradually increasing quantities of sewage, from 24,000 to 97,000 gallons per acre per day. Even at this large rate the oxygen absorbed was reduced by about 80 per cent., and the effluents contained on an average 7·76 parts of nitric acid per 100,000 (2·43 at first and as much as 12·69 later). The number of bacteria in the effluent varied between about 100,000 and 200,000, averaging 140,000 per c.c.

In 1894 a filter was constructed of coarser gravel, and worked at the rate of rather more than 13,000 gallons per acre per day. Then experiments were tried in which the suspended matter was removed by a preliminary chemical precipitation or by means of coke filters. Some filters were provided with artificial aeration, and were worked at the rate of about 350,000 gallons per acre per day. Even at this high rate a reduction in the oxygen absorbed of 60 to 85 per cent. was obtained, but the pores of the filter began to show signs of clogging.

As time went on a large number of towns in Massachusetts were compelled to treat their sewage by land filtration. The process was adopted by twenty-three towns, having populations ranging from 2000 to 118,000. I have already described elsewhere some of the more important of these works, after personal inspection. In this chapter I will therefore limit the description to two.

Practical Applications of the Lawrence Experiments.—*Brockton.*—Brockton is a manufacturing town, situated not far from Boston, on the banks of the Salisbury Plain River. In 1900 the population was 40,000; and, since 1880, the town has possessed waterworks supplying, in 1903, a million and a quarter gallons daily, equivalent to 31 gallons per head of population. In 1893 Brockton was sewered on the separate system. The sewage is received in a collecting sump, from which it is pumped a few miles to the purification works. The effluent from the works first enters a small tributary of the Salisbury Plain River, which itself joins the Taunton River. The importance of sewage purification for Brockton is largely due to the fact that the Taunton River flows through the town of Taunton. The total length of the sewers, which are chiefly of earthenware, is over thirty miles, and connected with these are about 2000 buildings with about sixty manufactories. Some of the sewers are laid in the subsoil water. Figs. 79 and 80 show what precautionary measures were adopted to prevent the subsoil water from entering the sewers. In spite of these measures, however, before the sewers were brought into operation it was found that 13,000 gallons of subsoil water entered the sewers daily in a length of about 650 yards. The whole sewerage system carried off daily about 100,000 gallons of subsoil water and during floods more than 280,000 gallons. Although the sewerage had been carefully carried out on the separate system, it was found, when operations were commenced, that the volume of sewage reaching the works on wet days was sometimes three times as great as on dry days. In 1903, for example, the minimum daily flow was 462,000, the maximum 1,396,560, and the average 731,060 gallons. These figures yield for the population (25,000) connected with the sewers a volume of sewage equal to a minimum of 18·48, a maximum of 55·88, and an average of 29·26 gallons per head. The figures serve to emphasise the necessity for towns to keep a continual record of the flow of sewage.

The sewage flows by gravitation into a covered collecting chamber, having a capacity of rather more than 440,000 gallons. This is pumped empty every evening, and is then able to take the night sewage, also allowing the pumping to be restricted to the daytime. Before entering the collecting chamber, the sewage passes a rough screen, which only retains about 1·5 cwts. of solids per day, and these are burnt under the boilers. The sediment is not removed and carted away from the collecting chamber, but is stirred up and pumped to the sewage works, where it is treated separately.

From the collecting chamber the sewage is pumped through a rising main, against a head of 42 feet, to the sewage works. The rising main is 3·3 miles long and 2 feet in diameter. At the sewage works an area of 39 acres is provided. This land is level, and naturally suitable, and within a radius of half a mile there are very few houses. In 1903, twenty-three filter beds had been constructed (fig. 81), covering an area of about 22 acres, and the preparation of other seven beds was contemplated. From nineteen of the filters, besides the upper loamy layer, the native soil had been removed in order to expose the lower layers of sand and gravel. From the other four beds only the loam had been removed. The size of the sand was 90 per cent. over 0·04 mm., that of the gravel 90 per cent. over 0·75 mm

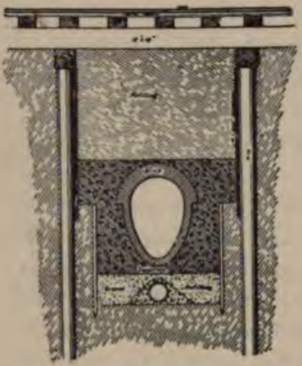


FIG. 79.—Construction of Sewers to exclude Subsoil Water (Brockton).

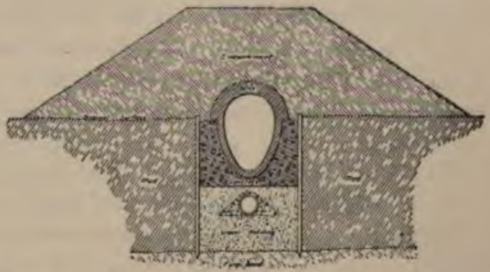


FIG. 80.—Construction of Sewers to exclude Subsoil Water (Brockton).

The filters were only drained where layers of very fine sand or clay occurred. The drains were then laid 7 to 9 feet deep and about 10 or 11 yards apart. Since the filters came into operation, various springs have made their appearance in the banks of the stream which receives the effluent, and these are considered to be the purified sewage.

The sludgy portion of the sewage from the bottom of the collecting chamber is allowed to remain in the rising main over night, and is then pumped in the morning on to four special beds.

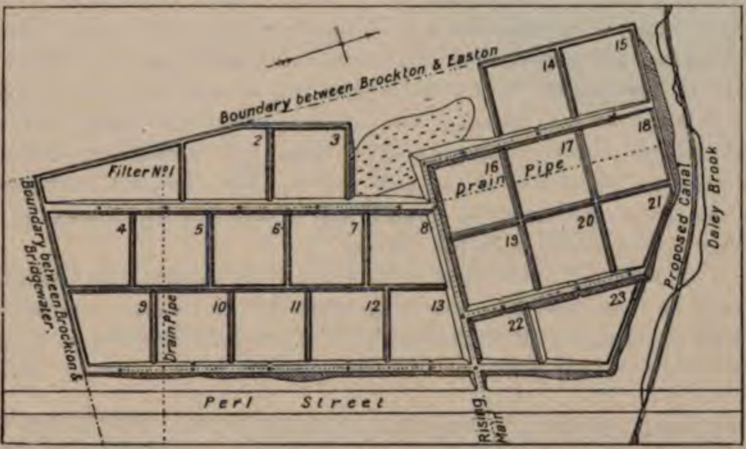


FIG. 81.—Intermittent Filtration Works (Brockton).

The duration of the flow on to each single bed is on the average thirty minutes. The sewage is conducted on to the beds by means of channels, the bottoms of which are of concrete, and the sides, 12 inches high, of wood. Openings are provided in the sides every 12 yards, and after each opening the cross-section of the channel is lessened (see fig. 82).

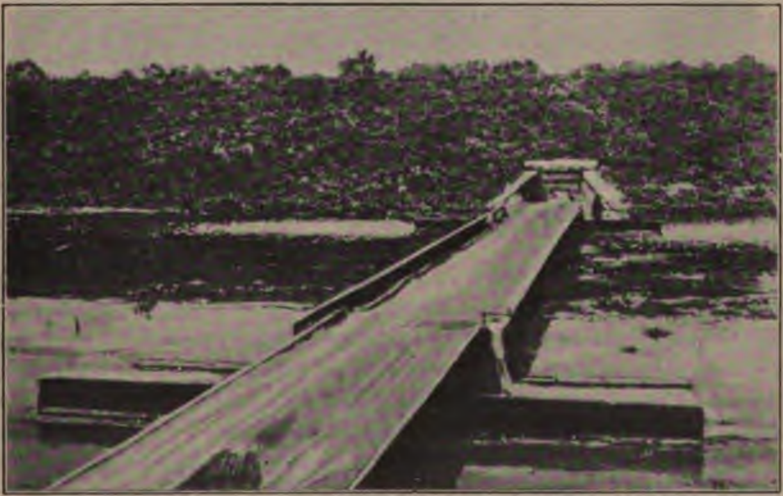


FIG. 82.—Distribution of Sewage in Filters.

The four filters which receive the sludge from the bottom of the collecting chamber are raked over after receiving about twenty doses. The rakings from these beds have amounted to about 1700 tons per annum, and have been sold to the farmers for about £30. The remaining filters required little or no attention, except an occasional removal of grass or weeds from the surface. A few of the beds have been yearly planted with maize, and experiments have been tried with peas and sunflowers. Maize is, however, the most suitable, and can be sold at a small profit if the beds are not overworked. The profit is, however, so small that it is intended to abandon the growth of crops. In autumn, furrows are ploughed on the surface of the beds (see fig. 83). Ice and snow remain on the top of the ridges so formed, and a sufficient distribution of the sewage takes place through the furrows.

With reference to the keen frosts which often occur in Massachusetts it may be mentioned that the temperature of the sewage entering the collecting chamber is at a minimum (7°·1 C.) in February and at a maximum (15°·8 C.) in September. The temperature of the sewage entering the filters is approximately the same. The effluents from the filters show a minimum temperature (5°·2 C.) in February and a maximum (15°·7 C.) in September.

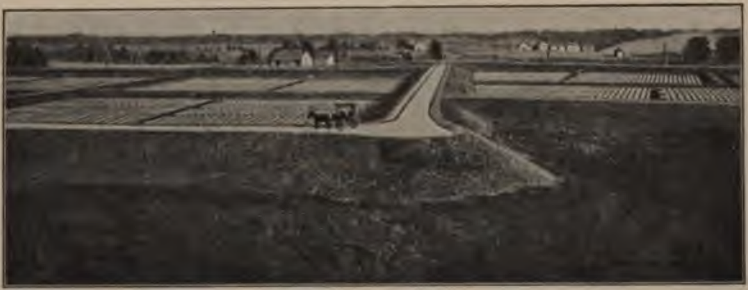


FIG. 83.—Furrows on the Surface of Filters.

Under the above-described unusually favourable conditions, the capacity of the land filters is of special interest. On the average, only 0·03 cubic yard of sewage can be purified on one square yard of surface. The sewage is chiefly domestic, but the numerous shoe factories produce fairly large volumes of concentrated black refuse. The sewage is however, as we have already seen, considerably diluted with subsoil water.

79 dec ff

Details as to the character of the sewage and of the sludgy sewage from the bottom of the collecting chamber are given in the following table. I have selected the analytical results of 1897 and 1903, in order to show that the sewage is getting more concentrated. The figures given are averages taken from analyses regularly performed by a chemist, for whom a laboratory has been provided at the sewage works.

As regards the working of the filters, the following particulars, culled *from the* report for 1902, may be of interest. Most of the filters cover an

BROCKTON. CHEMICAL ANALYSES OF CRUDE SEWAGE (YEARLY AVERAGES).
(Results expressed in parts per 100,000.)

Year.	Total Solids.		Solids in Suspension.		Solids in Solution.		Ammonia (NH_3).				Chlorides (Cl).	Oxygen absorbed.	
								Albuminoid.					
	Total.	Loss on Ignition.	Total.	Loss on Ignition.	Total.	Loss on Ignition.	Free.	Total.	In Solution.	In Suspension.		Total.	In Solution.
1897	39·15	18·40	9·83	7·99	29·32	10·41	2·36	0·57	0·33	0·24	6·29	3·63	1·97
1903	81·88	42·52	19·46	17·34	62·42	25·18	5·21	0·96	0·50	0·46	13·18	16·08	9·09
					Chemical Analyses of Sludgy Sewage.								
1897	234·00	167·11	197·51	151·64	36·49	15·47	4·41	3·76	0·82	2·94	6·82	24·40	3·49
1903	472·92	374·42	403·99	347·10	69·02	27·32	6·19	7·05	0·60	6·45	13·90	70·56	10·18

area of one acre. On the average they received a dose of sewage every third day, some as many as 168 doses in the year, and the average volume of sewage per dose was 70,000 to 90,000 gallons; sometimes as much as 130,000 gallons was discharged to a filter at one time and the maximum volume so discharged was 220,000 gallons. One filter received, however, 440,000 gallons on one occasion. From these figures the average daily quantity of sewage dealt with by a single filter was 23,540 gallons.

The sludgy sewage from the bottom of the collecting chamber was discharged temporarily to two of the filters besides the four previously mentioned. Each of the four filters received a charge every fourth day, the volume discharged being about 70,000 gallons, giving an average daily volume per filter of about 18,000 gallons.

The effluents from the filters were clear and colourless and devoid of smell. If the filters were overworked they yielded effluents containing iron. The presence of iron in the effluents from artificial biological filters may also be regarded as a sign of overworking.

The average results of the analyses of the effluents for the years 1897 and 1903 are given in the following table:—

CHEMICAL ANALYSES OF PURIFIED SEWAGE (YEARLY AVERAGES).
(Results expressed in parts per 100,000.)

Year.	Total Solids.	Ammonia (NH_3).		Chlorides (Cl).	Nitrogen.		Oxygen Absorbed.	Iron.
		Free.	Albuminoid.		Nitric.	Nitrous.		
1897	27·75	0·091	0·010	4·80	1·224	0·002	0·11	0·0003
1903	53·17	0·225	0·017	11·13	3·075	0·010	0·33	0·0601

Hence, for the year 1903 the free ammonia in the sewage was reduced by 95·8 per cent., the albuminoid ammonia by 98·9 per cent., and the oxygen absorbed by 98·5 per cent.

In calculating the costs it must be remembered that the eight hours' working day is paid for at the rate of nine shillings and sixpence, and hence the figures are scarcely applicable to German conditions. The figures are:—

Purchase of land	£ 1,957·5
Preparation of filter areas	10,664·0
Rising main	15,898·0
Collecting chamber	6,331·0
Pumping station	9,452·7

In 1896 the working expenses amounted to £450, and by 1903 they had gradually risen to £750. Against these figures must be placed an income of £30 to £90, derived from the sale of sludge and maize.

Framingham.—The sewage works of Framingham may also be described, since they are one of the oldest works in Massachusetts constructed on the system of intermittent filtration. South Framingham, with a population of 7000, lies within the watershed of the Sudbury River, above the point at which the water supply of the city of Boston is derived from this river. The town is also situated in the gathering ground of Lake Cochituate, the water of which is used to supply the Metropolitan District of Boston. For these reasons it was necessary to carefully purify the sewage of the town, including that of a prison with 350 inmates. The town was sewered on the separate system, the length of the sewers being 15 to 16 miles, to which were connected, besides 1165 dwelling-houses, 27 workshops, 9 manufactories, 6 schools, 3 hotels, and 4 churches.

In spite of the careful adoption of the separate system of sewerage, the volume of the sewage here also showed considerable variations. In 1903 the average daily volume was 542,960 gallons, with a minimum of 334,840 and a maximum of 1,532,080 gallons. Per head of the population connected to the sewers, these figures give a volume of sewage on the average of 72·4 gallons per day, with a minimum of 44·7 and a maximum of 204·4. In laying the sewers every effort was made to ensure separate drainage of the subsoil water, but this was not the case with extensions undertaken later.

It may be of interest to state that in the prison, in 1898, the water nsumption amounted to 82·9 gallons per head per day.

The trade refuse entering the sewers includes that from a colour works, 33,000 gallons, and that from a hat factory, 15,000 gallons y.

ore entering a collecting chamber, the sewage passes through a screen, from which about a barrowful of solids are removed twice a week and burnt under boilers. The capacity of the collecting chamber is about 350,000 gallons, thus permitting of the pumping being restricted to the daytime. As at Brockton, the sediment in the collecting chamber is pumped to the sewage works, about two miles away. The land upon which the sewage works have been constructed is level ground, with coarse gravelly soil, about 100 acres in extent, which was formerly planted with trees. The neighbourhood, within a radius of half a mile, with the exception of six houses, is uninhabited.

Eighteen filters, with a total area of 20 acres, have been brought into operation. The work of preparing the land, besides a small amount of levelling, consisted in the removal of the trees and the formation of earthen banks round each of the filters. On one of the filters the tree roots were allowed to remain. The native soil was not removed in any case. Only eleven of the eighteen filters are underdrained, and these have only one set of drains each, placed in the middle of the filter at a depth of six feet. Several springs which have made their appearance on the banks of the river are considered to be the effluents from the seven undrained filters. In some of the filters an open channel has been constructed along the earthen banks surrounding the filter, and from this channel the sewage is discharged on to the filter at various points. Since some of the filters are not quite level, the distribution of the sewage is often unsatisfactory. In some cases the sewage is placed upon the filters at two points, by means of pipes passing through the earthen banks, and the sewage must distribute itself as best it can from these points.

During the summer months the whole of the daily flow of sewage is discharged on to one filter each day. In winter and spring two or three filters are used each day. Each filter is therefore allowed to rest for several days. Throughout the year the amount of sewage treated was equal to a daily average of 0·03 cubic yard per square yard of filter area. = 9 ton This figure must not be confused with the actual amount of sewage placed on the filter on any single day; for this amount was about 0·29 cubic yard per square yard of surface; but as the filters were only dosed on an average thirty-six times in the year, they only received a filling every tenth day. During 1903 some filters were dosed only fifteen times and others sixty-nine times.

The attention bestowed on the filters is limited to raking over, in the spring, the surface of those beds which show poor distribution. Besides this, the beds are ploughed every year and planted with maize; but beyond keeping the earthen banks in order and gathering the maize crops, nothing further is done. In autumn the maize is cut six inches above the ground. The little hillock thus remaining around each stalk serves to support any layer of ice which may be formed in winter. The sewage can thus be treated underneath the ice throughout the winter, Not so — ridiculous. possibly as -4°C.

although the average temperature for two months is – 13° C. and the thermometer often registers – 23° C. A view of the Framingham works in winter, with the snow a foot deep, is shown in fig. 84, from which it may be seen how the filters continue in operation underneath the snow.

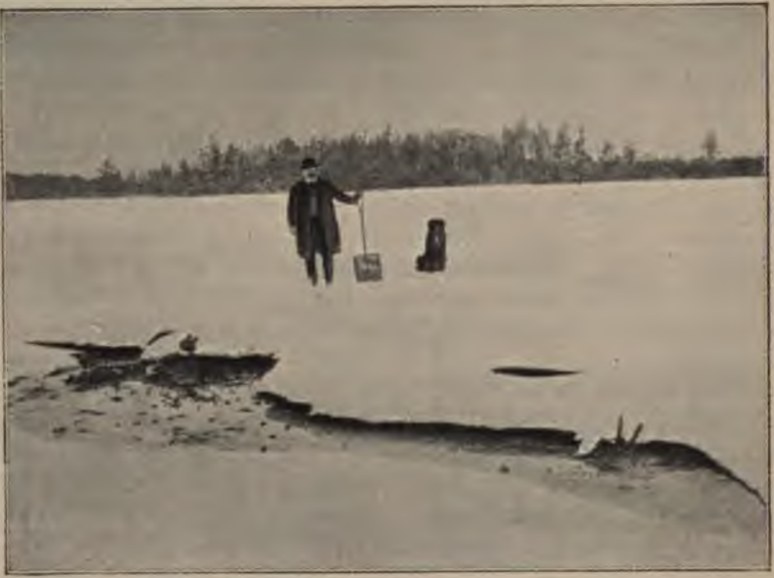


FIG. 84.—Intermittent Filter in Winter (Framingham).

The average temperature of the sewage reaching the filters from January to May 1903 was 7·2° C.; this rose in June to 8·9°, and reached a maximum of 15·5° in August. The sewage of South Framingham, like that of Brockton, is regarded as very concentrated in comparison with the sewage of other American towns. Analyses are made once a month, and the average results for 1903 are given in the following table:—

CHEMICAL ANALYSIS OF FRAMINGHAM CRUDE SEWAGE (YEARLY AVERAGE OF MONTHLY ANALYSES).

(Results expressed in parts per 100,000.)

Year.	Total Solids.		Solids in Solution.		Solids in Suspension.		Ammonia (NH_3).				Chlorides (Cl).	Oxygen absorbed.	
							Free.	Albuminoid.					
	Total.	Loss on Ignition.	Total.	Loss on Ignition.	Total.	Loss on Ignition.		Total.	In Solution.	In Suspension.		Total.	In Solution.
1903	58·77	29·88	37·53	13·66	21·24	16·22	3·17	0·79	0·41	0·38	6·99	4·67	2·69

The following table contains the results of the analyses of the effluents from three sources for the same year :—

CHEMICAL ANALYSES OF EFFLUENTS FROM FRAMINGHAM FILTERS.
(YEARLY AVERAGE OF MONTHLY ANALYSES.)
(Results expressed in parts per 100,000.)

	Year.	Total Solids.	Ammonia (NH_3).		Chlorides (Cl).	Nitrogen.		Oxygen absorbed.	Iron.
			Free.	Albuminoid.		Nitric.	Nitrous.		
Eastern Drain	1903	29·15	0·236	0·023	5·32	1·002	0·017	0·31	0·044
Western Drain	1903	27·87	0·198	0·015	5·03	0·969	0·013	0·21	0·028
Spring . .	1903	21·06	0·0004	0·002	3·81	0·910	Nil.	0·04	0·005

The purification, judged on the effluent from the eastern drain, was 92·6 per cent. as regards free ammonia, 97·1 per cent. on the albuminoid ammonia, and 93·2 per cent. on the oxygen absorbed. The other effluents showed a higher percentage of purification. Even during the coldest months, December to May, the percentage reduction of the free ammonia was 91·9, of the albuminoid ammonia 97·4, and of the oxygen absorbed 90·9.

The cost of preparation of the 20 acres, including drainage, is given as about £2100, the cost of labour being about double what it is in Germany. The figures for the total cost are :—

Collecting chamber (capacity 358,600 gallons) and rising main	about	£8,155
Pumping station	about	3,330
Pumps (capacity 1,665,400 gallons per day) . .		1,385
Purchase of land (100 acres)		1,225
Construction of filters (20 acres)		2,120
Total . .	about	£16,215

The working expenses of the filters cannot be calculated, because labourers are only employed a portion of their time on the work. The sale of the maize crops during the last six years has realised an annual income of £85, from which 10 per cent. must be deducted for commission. The working expenses at the pumping station amounted to £850 per annum.

The above descriptions serve to show how very simple is the whole operation of intermittent land filtration. It is so simple that one would suppose mistakes to be impossible; yet in practice the almost invariable tendency to depart from even very simple rules has to be taken into account. The excellent results obtained by this method in Massachusetts are largely due to the careful supervision exercised by the officials of the State Board of Health, who not only examine the plans of schemes and supervise the construction of works, but also continually inspect the operations carried on at the works.

Any deviation from experimentally determined rules for the operation of intermittent filtration, or indeed of any process of sewage purification, is at once followed by a decreased efficiency. A municipal engineer, who has had much experience in this direction, declared in his report: "An intermittent filter must be treated like a living thing. If it is overfed, its digestion is interfered with. Each filter becomes accustomed, not only to a definite dose of sewage, but also to sewage of a definite character, and any sudden change from these conditions disturbs the working of the filter for a shorter or longer period. This does not mean that expensive supervision should be exercised, nor that the filters cannot accommodate themselves to changes within certain limits. Under all circumstances, however, operations must be carried on in a methodical manner." These remarks should be taken to heart by all those entrusted with the management of land filtration works.

Lawrence Method of Soil Examination.—Twenty years of experience have shown how land filtration can be applied in Massachusetts, even under adverse climatic conditions, so as to produce very satisfactory results. A method was, however, early sought by which it could be determined whether or not a sample of soil was suitable for land filtration. Experience has shown that certain kinds of soil, such as very heavy loam and clay, are unsuitable. Frankland considered peat as suitable, but at Lawrence peat has been found to be useless. Of other kinds of soil also, the assumption could be made without investigation that they would be unsuitable. The results of very extensive comparative investigations have been published in the Twenty-Third Report of the Massachusetts State Board of Health for the year 1891.

The method of soil examination which has been worked out at Lawrence is as follows: The sample of soil is dried and passed through a series of sieves, the meshes of which, expressed in the metric system, are about 10, 5, 2, 1, 0·5, 0·25, and 0·1 mm. A weighed quantity (say 5 grammes) of the soil which passes through the finest of these sieves is mixed with 200 c.c. of distilled water in a beaker, and air is blown through the mixture to effect an even distribution of the soil in the water. Settlement is then allowed to proceed for fifteen seconds, at the end of which time the supernatant liquid is decanted. The size of the particles composing the sediment is regarded as 0·1 to 0·05 mm. Air is blown through the decanted liquid, and sedimentation is allowed to proceed for thirty seconds. The size of the particles composing the sediment in this case is regarded as 0·05 to 0·03 mm. The process is repeated, settlement being allowed to proceed for sixty seconds, the size of the particles in the sediment varying from 0·03 to 0·01 mm. The particles finally remaining in the liquid are regarded as organic matter. All the above samples are *dried at* 105° C. until constant in weight.

The above method divides the sample of soil into eleven portions, which are weighed separately. The sum of the weights of the separate portions is equal to the weight of dried soil originally taken, less that which has been lost during the levigation process. It is advisable to use not less than 200 grammes of dried soil; and if exactly 200 grammes be taken, the weights of the separate portions divided by two give the percentages of these portions. The accompanying table gives the result of the examination of one of the filters in operation at the Lawrence Experiment Station:—

LAWRENCE FILTER NO. 6. RESULT OF EXAMINATION OF SIZE OF MATERIAL.

Size in mm., less than	12·6	6·2	2·2	0·98	0·46	0·24	0·12	0·06	0·03	0·01
Per cent. . . .	83	73	57	32	13	7	4	2	0·5	0

The curve shown in fig. 85 has been constructed from these figures, the ordinates representing the percentages and the abscissæ the size of the material. The figures along the axis of abscissæ are the actual sizes; but in order to prevent the diagram from being uselessly long, the distances are proportional to the logarithms of these figures.

In Massachusetts the conclusion has been drawn that the finer particles, up to 10 per cent. of the total material, exert the same influence on the action of the filter as the remaining 90 per cent. This influence is explained as follows: In a mixture containing particles of various sizes, the finer particles occupy the spaces between the larger particles. Water can easily flow over the surface of the larger particles, but, owing to the greater influence of frictional resistance and capillary attraction, it is forced to trickle slowly through the finer material. Samples of soil have been shown to be most suitable, as regards percolation and filtering action, when they contained 10 per cent. of very fine material, not, however, in the form of dust, which would clog up the pores of the larger material.

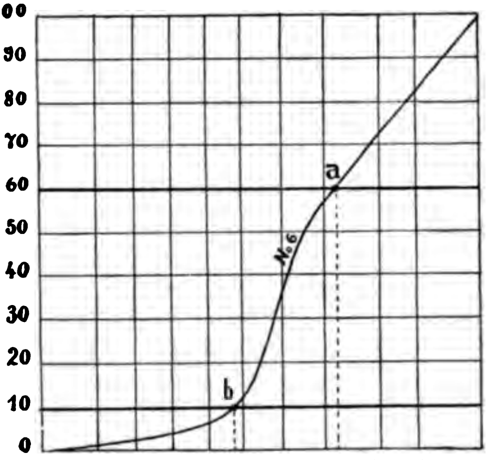


FIG. 85.—Size of Material in Filter No. 6.

For this reason the horizontal line representing 10 per cent. has been drawn rather thicker, and the point of intersection of this line with the curve representing the size of the material will be further to the right the coarser the material. The projection of this point of intersection on the axis of abscissæ should lie between 0·24 and 0·46 in the case of soils suitable for intermittent filtration. This figure is termed the "effective size" of the material. From the diagram (fig. 85) it will be seen that so far as the effective size is concerned, the material of which Filter No. 6 is composed is suitable for the purpose, the effective size being 0·35.

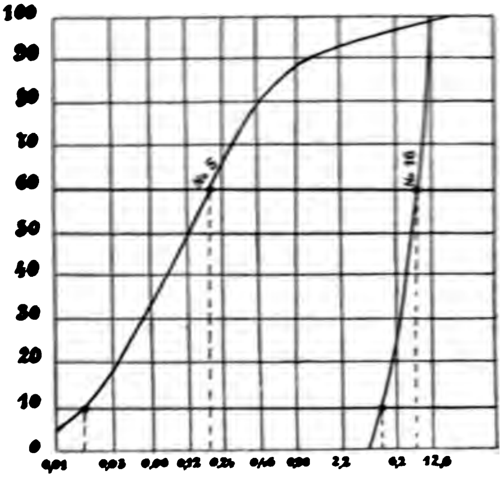


Fig. 86.—Size of Material in Filters No. 5 and No. 16.

Besides the effective size, a certain importance attaches to the so-called "uniformity coefficient" of the soil. This figure, like that for the effective size, has been obtained in an empirical manner as follows: It is assumed that the mean size of the 90 per cent. of material remaining after the subtraction of the 10 per cent. which is below the effective size, lies at the point where the curve intersects the horizontal line representing 60 per cent. This horizontal line is also drawn rather thicker in the diagram (fig. 85). If we call this point of intersection *a*, and the point where the line representing 10 per cent. cuts the curve *b*, the projection of *a* on the axis of abscissæ is at 2·73 and the projection of *b* at 0·35. On dividing 2·73 by 0·35, we obtain the ratio 7·8, which is termed the uniformity coefficient. With very coarse material this ratio is high, 10 or more, and with fine material it is lower, 2 or less. It has been found that material with an effective size of 0·3 and a uniformity coefficient between 2 and 5 is specially suitable for filtration purposes. In the above diagram (fig. 85) the value of the uniformity coefficient is rather high, but the material may nevertheless be considered as well suited for intermittent land filtration.

The following table and the curves (fig. 86) show the results obtained from two other filters, as compared with Filter No. 6:—

RESULTS OF EXAMINATION OF SIZE OF MATERIAL.

Size in mm., less than	12·6	6·2	2·2	0·98	0·46	0·24	0·12	0·06	0·03	0·01
Filter No. 5, per cent.	99	96	92	89	80	67	51	33	16	6
Filter No. 16, per cent.	98	27	0	...	...	...	...	...	...	...

Judged by the above-described method, the material from Filter No. 5 would be unsuitable, for the effective size is very small (0·02). The material from Filter No. 16 is, on the other hand, too large, the effective size being 5. An even distribution of the sewage on this filter could only be obtained by the adoption of some special form of distributing apparatus.

By the "water-retaining capacity" of a soil is to be understood the volume of water which remains in the soil after first drying the soil, filling it with water, and allowing the excess water to drain away. In soils having suitable values for the effective size and uniformity coefficient, the water-retaining capacity is usually 16 to 18 per cent. of the volume occupied by the soil. If the effective size is too small, the water-retaining capacity is large, and *vice versa.*

If the water-retaining capacity of a soil is subtracted from the volume occupied by the pores, a figure is obtained which is termed the "air capacity." A soil in which the water-retaining capacity is almost as large as the volume of the pores is not suitable for intermittent filtration, because, when the sewage gets into the soil, too little air is available.

The experience gained in Massachusetts indicates that the volume of sewage applied at a single dose to intermittent filters should not exceed the water-retaining capacity of the filter.

Clogging of the Filters.—The sewage works at Framingham have been in operation for twenty years, and others constructed on similar principles have been working for an almost equal period.

LIST OF SEWAGE WORKS IN MASSACHUSETTS, WITH POPULATION AND DATE WHEN WORKS WERE BROUGHT INTO OPERATION.

Name of Town.	Population (1900 census)	Sewage Purification by Intermittent Filtration introduced in
Andover	6,813	1898
Brockton	40,063	1893–94
Clinton	13,667	1898–99
Concord	5,652	1898–99
Gardner	10,813	1891
Leicester	3,416	1894
Marlborough	13,609	1890–91
Natick	9,488	1895–96
Pittsfield	21,766	1890
Spencer	7,627	1897
Westborough	5,400	1891–92
Worcester	118,421	1890

During their twenty years' existence the Framingham filters have continuously converted the sewage into an effluent equal to that from the best irrigation works, without showing any signs of the difficulties which Frankland feared might arise in carrying out the process on a large scale. Until quite recently it was thought that Frankland's prophecy with regard to the clogging up of the soil would not be realised, and that land filtration works would be able to treat sewage for ever. Recently, however, the oldest filters at the Lawrence Experiment Station have yielded effluents containing diminished quantities of nitric acid, especially in winter, and at the same time increased quantities of free and albuminoid ammonia. The frost, which scarcely penetrated beneath the surface of the new filters, is now penetrating to a depth of 6 or 8 inches. This is thought to be due to a gradual sludging up of the filters. The immense practical importance of this question has been the cause of various attempts to meet this difficulty. In the autumn of 1903 the surface of the filters was broken up and raked into furrows, so that the distribution of the sewage was only effected by means of the furrows. The material which had been removed to form the furrows was piled up between the furrows into ridges, with the consequence that the covering of ice during the following winter remained on the top of the ridges, the frost did not penetrate so deep into the filters, and increased quantities of nitric acid appeared in the effluent. On some filters deeper furrows were dug out and again partly filled with fresh gravel, the sewage being distributed only on the fresh material. This left a portion of the filter surface fallow, and experiments were undertaken to see whether and how far the matters which had choked the filter would decompose during a long period of rest. Part of the material was easily decomposed and nitrified, but the larger portion withstood the action of micro-organisms. For example, at one part of the filter the amount of albuminoid ammonia sank, during a short period of resting, from 74·4 to 46·05 parts per 100,000 of sandy filtering material, a reduction of 38 per cent. Three months later, at the same place, the amount was still 45·9.

In the deeper layers of the filter much smaller quantities of organic matter were found, as is evident from the following table :—

ORGANIC MATTER FOUND IN THE FILTERING MATERIAL AT VARIOUS DEPTHS OF INTERMITTENT FILTERS.

Approximate Depth (in cm.)	Albuminoid Ammonia (NH_3) (parts per 100,000).	
	Nov. 23, 1903.	Oct. 10, 1904.
15	46·3	47·0
22	58·5	45·1
30	18·2	39·0
38	13·6	14·0
45	16·8	11·9
60	7·2	9·2
90	4·9	6·3
120	3·3	5·0
150	4·6	3·4

As will be seen from the table, the experiment was performed a second time after continuous working for a year, but there was no appreciable increase in the amount of nitrogenous matter in the deeper layers.

Small experimental filters were prepared from the clogged upper layers of the filter sand, and these were dosed with clean water instead of sewage. The effluents contained as much as 15 parts of nitric acid per 100,000, thus indicating a decomposition and mineralisation of the retained solids. After a time, however, the formation of nitric acid ceased, and some of the organic matters still remained in the sand, thus indicating that a large portion could not be broken down and mineralised. Of each pound of total nitrogen retained by the sand from the sewage, only a quarter pound was found in the effluent in the forms of free ammonia, nitrous and nitric nitrogen. A considerable portion had disappeared in other forms. This question will be dealt with more fully later.

Attempts were made to induce further nitrification in these small experimental filters by adding lime, potassium carbonate, hydrochloric acid, common salt, and other substances, but the experiments were fruitless. Inoculation with pure cultures of nitrifying organisms was also tried in vain. Only when easily nitrifiable nitrogenous substances were placed on the filter was nitric acid obtained in the effluent.

Comparative experiments on the loss on ignition of the filtering material showed an increase from 0·42 per cent., originally, to 1·16 per cent. The loss on ignition of the whole of the filtering material was originally 467 lbs., and after seventeen years working it had increased by 822 lbs., of which 450 lbs. (*i.e.* over 50 per cent.) was within one foot of the surface.

The better results obtained by furrowing the surface of the filters are not regarded favourably in Massachusetts, because in this manner the accumulation of undecomposable organic matter only takes place at lower depths of the filter. The deposition of organic matter at various depths may be seen from the following table :—

ACCUMULATION OF ORGANIC MATTER IN FILTER NO. 1.

(Calculated from the Loss on Ignition of the Filtering Material.)

Depth in inches.	Loss on Ignition (per cent.).	Increased Loss on Ignition (per cent.).	Weight of Sand (kilos.).	Loss on Ignition (kilos.).	Loss on Ignition (kilos. per acre).
0–6	2·53	2·11	5,045	106 5	21,044
6–9	2·51	2·09	2,522	52·7	10,410
9–12	2·20	1·78	2,522	44·9	8,877
12–15	1·05	0·62	2,522	15·6	3,093
15–18	0·91	0·49	2,522	12·4	2,448
18–24	0·90	0·48	5,045	27·2	5,371
24–36	0·86	0·44	10,090	44·4	8,778
36–48	0·82	0·40	10,090	40·4	7,980
48–60	0·71	0·29	10,090	29·1	5,756

The above experiments lead to the conclusion that the filtration process gives rise to the accumulation within the filter of a considerable amount of organic matter of a very stable nature. This organic matter is comparable to the humus of the soil, which remains unchanged from year to year, unless a very intensive cultivation is carried on. At first sight, therefore, it would appear that filtration, without the cultivation of crops, *i.e.* without the adoption of irrigation, would not lead to the object in view. It must be borne in mind, however, that for seventeen years the filters have been receiving sewage at a rate ten to twenty times as high as could possibly have been treated on the same area by irrigation. Moreover, the clogging does not extend to more than about a foot below the surface, and hence it can at most be a question of removing the upper layer of sand and either washing and replacing it or providing fresh material.

The applicability of land filtration does not appear to me to be seriously called in question by this gradual clogging of the soil. The cost of regeneration by some rational method should be comparatively small.

In Germany intermittent filtration has not been adopted to any great extent. Cases do occur in which sewage, chiefly from manufacturing operations, has been allowed to trickle through sand, often in the same manner as was adopted forty years ago at Ealing, where Frankland calculated that the filter surface was six hundred times too small. Such cases can hardly be considered as intermittent land filtration, and they will therefore not be dealt with here.

Where a thorough purification of the sewage is necessary, and where irrigation cannot be adopted, there is at the present day in Germany a tendency to adopt artificial biological methods. In some districts these methods are very expensive, because filtering medium, such as clinker, broken bricks, stones, etc., is not found in the neighbourhood. For land filtration only about one-tenth as much land is necessary as for irrigation, and hence preparatory work may be undertaken on the smaller area, which would be out of the question for the large area necessary for irrigation. A case is known to me in which land was made very suitable for intermittent filtration by simply removing the surface layer of almost impermeable soil to a depth of about half a yard. It seems to me quite possible that similar conditions prevail in other places, and I have formed the impression that land filtration might attain practical importance in Germany.

Maturing of Filters.—The question as to the time of action and period of rest most suitable for land filters seems to require further elucidation. Frankland recommended dosing the filters for six hours out of twenty-four. At Brockton, as we have seen, the daily quantity of sewage is discharged to a filter within half an hour, whilst at Framingham the sewage is discharged on to one filter for a whole day. The question seems to be of immense practical importance and one which lends itself to experimental inquiry.

If sewage is discharged on to a sterile sandy soil, the effluent is not purified at first. A sand filter 1 yard deep was treated every third day with 6 inches of septic sewage, equivalent to 2 inches per day; even after four doses the effluent showed a reduction in the oxygen absorbed of less than 50 per cent. and was putrescible. After the fifth dose the effluent showed a reduction in the oxygen absorbed of over 60 per cent., and was non-putrescible. The results are shown in diagrammatic form in fig. 87.

In Massachusetts this maturing of the filters is measured by the time which elapses before nitrates appear in the effluent. Land-filter effluents containing nitrates are usually non-putrescible. In Massachusetts the period required by the filters to reach this stage was about eight days in summer and two to three months in winter.

If a quantity of sewage, equal to the water-retaining capacity of the filter, is poured over a "mature" filter, 3 feet deep, ten to twenty minutes elapse before the sewage is discharged from the bottom of the filter, if the filtering material is suitable. It is generally assumed that this effluent is derived from the preceding dose of sewage and not from that just poured on to the filter.[1] If, for example, a filter 3 feet deep and with 1 square yard of surface, constructed of material to be described later, be dosed with about 45 gallons of sewage, only 4·5 gallons are discharged from the filter. If now 2 gallons are poured on to the filter, either at once or after a few days, 2 gallons are discharged; if 20 gallons are poured on, 20 gallons are discharged, and so on. Thus the idea has become prevalent that of the

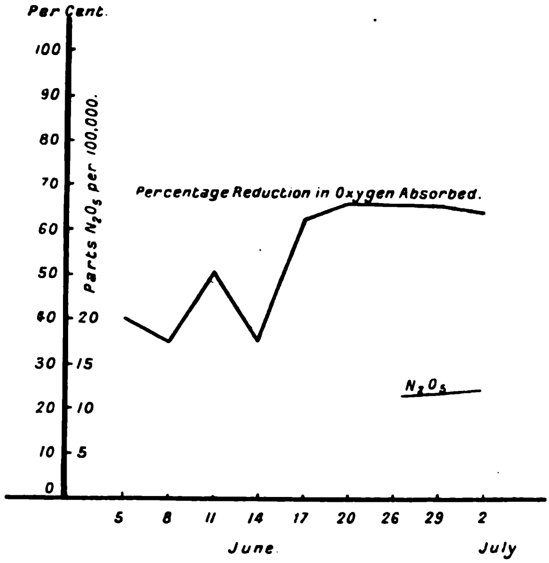


FIG. 87.—Purification effected by Intermittent Filtration.

---

[1] In the Twenty-Second Report of the Massachusetts State Board of Health an opinion is expressed which is the same as that of the author. Other opinions seem, however, to have prevailed at that time, even in Massachusetts.

fresh sewage poured on to the filter a volume equal to the water-retaining capacity remained in the filter, and only displaced water which was previously in the filter, so long as the charge was below the water-retaining capacity of the filter. On account of observations made with artificial biological filters, I have had my doubts as to the correctness of the above view, and, in order to solve the problem, I have had substances added to the sewage. Sodium chloride is not very suitable for this purpose, as it already exists in sewage. Potassium iodide and colouring matters, such as fluorescein, which are not absorbed, are more suitable. When such substances were added to sewage, and 44 gallons of the sewage poured over a filter, 1 yard deep, and having 1 square yard of surface, with a water-retaining capacity of 18 per cent., *i.e.* retaining 40 gallons of water, and the effluent collected in quarter-gallon portions, the fourth quarter-gallon contained potassium iodide or fluorescein in the same concentration as the sewage added. These experiments repeatedly gave the same result, and do not leave any doubt that the sewage entering the filter corresponds to the effluent obtained ten to thirty minutes later.

This experiment is all the more interesting because only a very small amount of the dissolved organic matters in the sewage remained in the effluent. Instead of organic nitrogen, nitric acid was present in the effluent. If, instead of sewage, a solution of albumen was used, the effluent was free from albumen. If the filter had been matured with a solution of albumen, the nitric acid in the effluent discharged ten to thirty minutes later corresponded to the amount of albumen added to the filter.

Absorption or Colloidal Theory of Sewage Purification.—How are these facts to be explained? As we have seen, Frankland assumed that the dissolved organic matters were oxidised by the oxygen of the air contained in the pores of the sand, as the sewage percolated through the soil. After the importance of micro-organisms for the process of nitrification had been demonstrated during the years 1877–1890 by the experiments of Schloesing and Müntz, as well as by those of Warington and Winogradsky, the action of the filters was explained in Massachusetts by assuming that the bacteria in the sewage and in the filter directly mineralised the organic matters during the slow flow of the sewage through the filter. This was a possible explanation so long as it could be assumed that the sewage remained for about three days in the filter; but when it was shown that the sewage left a 3-feet filter thoroughly purified within ten minutes, and shallower filters in shorter periods (*e.g.* an 18-inch filter in five minutes, an 8-inch filter in twenty-six seconds, and a 4-inch filter in twelve seconds), the above explanation fell to the ground. It cannot be assumed that micro-organisms decompose highly complex molecules of organic substances within a few minutes or seconds, with the formation of ammonia and nitrogen gas, and oxidise these substances to nitric acid, organic carbon to carbonic acid, organic sulphur to sulphuric acid, etc. It can only be *assumed that the dissolved organic matters are first separated from the* *sewage during its passage through the filter, and are retained in the filter to be decomposed and oxidised by the micro-organisms during the succeeding period of rest.*

Experiments in support of this explanation would have to be directed to three questions: (1) Mechanical filtration, (2) chemical combination, and (3) absorption.

With the question of *mechanical filtration* I dealt fully about ten years ago. It may be regarded as certain that filters retain mechanically the coarser suspended solids, and that when they begin to clog up the filter finer particles are retained by the sludge, so that the filtrate becomes gradually clearer as the clogging of the filter proceeds. The separation of the dissolved organic solids simply by mechanical filtration seems, however, impossible. The dissolved organic solids pass through the finest sand filter, and even through fine filter-paper or bacteria-proof earthenware filters, without suffering any appreciable diminution in quantity. Even solutions of albumen, which, as will be described later, would be most likely to be retained by mechanical filtration, yield filtrates containing almost exactly the same amount of organic matter as the original solution. A solution of albumen with an oxygen absorbed of 9·82 parts per 100,000, when filtered through a bacteria-proof Berkefeld filter, yielded a filtrate of which the oxygen absorbed was 8·2 parts per 100,000. Such a filter reduced the oxygen absorbed of a sample of sewage from 19·47 to 17·30 parts per 100,000. The process of filtration did not alter the character of the liquids, for both filtrates were still putrescible. In spite of such results it has recently been persistently maintained that the process of purification is a mechanical filtration. This erroneous hypothesis is probably due to irrelevant and misunderstood experiments on solutions of albumen, carried out by the aid of the ultramicroscope. By means of this instrument it was thought that it would be possible to show that in albumen solutions the albumen exists only in suspension; it was even expected that the molecules of albumen would be rendered visible by means of the ultramicroscope. Such ideas have been found to be erroneous. Moreover, so far as my numerous experiments on this point are able to show, the dissolved matter in domestic sewage is usually free from true albumen. The above considerations have convinced me that the action of sewage filters is not due to mechanical filtration.

So far as experiments with solutions of albumen and similar substances are able to show, *chemical combination* is also not the cause. In sewage, however, substances are usually present which might possibly unite with substances present in the filtering material. As an experiment I had a biological filter dosed with a dilute solution of acetic acid. Although the solution possessed a strongly acid reaction, the filter effluent was neutral and contained one-half of the acetic acid in the form of acetates. It would lead us too far to deal here with all the possible combinations between the constituents of the sewage and the material of the filters. It may, however, be mentioned that for some of the substances characteristic of sewage both chemical combination and absorption are possible; such substances are, for example, ammonia and sulphuretted hydrogen. Sometimes biological filters become black, due to the presence of large quantities of sulphide of iron; this is especially the case with overworked filters. In this case the sulphuretted hydrogen has been either directly or indirectly chemically combined with iron. If air is admitted to such filters, the sulphide of iron is oxidised with formation of sulphuric acid, and the black colour disappears. It is, however, a fact that the larger portion of the dissolved putrescible matters in sewage cannot be retained in the filters by chemical combination. Chemical reactions which would enable this to take place are unknown.

Hence, an explanation of the purification process must be sought in *absorption* phenomena. As early as 1897 I came to the conclusion that the biological purification of sewage is in all cases commenced by absorptive action. Since then this conclusion has been repeatedly submitted to the test of experiment, always with the result that it has been fully confirmed. From various sides, reasonable and unreasonable objections have been taken to my theory, but on investigation the objections to the absorption theory have been proved to be unfounded.

Bearing in mind the heterogeneous and continually varying composition of sewage, it appeared in the first instance necessary to work with solutions of the various substances which are present in sewage. The well-known fact that non-dialysable substances of high molecular weight, such as albumen, are more subject to absorption than simpler compounds, was the cause of many samples of domestic and town sewage being tested for albumen, in order to see whether the intense absorptive action exerted by a matured filter on the dissolved organic matters in sewage may be due to the presence of such colloids. The experiments have all shown the absence of albumen, but the presence of peptone-like products of the decomposition of albumen. These substances are dialysable, but they are absorbed like albumen. A strongly putrescible but dialysable solution of peptone may be converted by treatment on a matured intermittent filter in a few minutes into a non-putrescible liquid.

Recently it has been maintained that a correct explanation of the absorption theory is only possible after it has been shown that about 50 per cent. of the dissolved organic matter in sewage is not dialysable. Such an idea is erroneous, because after removal of 50 per cent. of the dissolved organic solids sewage still remains putrescible. Those who have worked at absorption problems know, not only that complex molecular undialysable substances are most readily absorbed, but also that dialysable substances can be absorbed. Experiments undertaken to show that my theory is wanting in this direction must therefore appear hopeless.

The numerous publications which have appeared in England under the *heading* of the "colloid theory" are largely by authors who were not aware of my own publications, as I have ascertained from personal intercourse with these authors.

The absorption theory has been gradually recognised as correct by ever increasing circles, so that, with the present-day literature at our disposal, any further description cf the theory scarcely seems desirable. Yet, in accordance with the wishes of some of my readers, I will give a short description of the main foundations of the theory so far as they are supported by experiments which have been carried out on intermittent filtration.

If sewage or other liquid containing dissolved organic matter is poured over a filter constructed of ignited sand, in quantities in excess of the water-retaining capacity of the filter, the effluent contains only slightly less organic matter than the original liquid. If the quantity of liquid poured on to the filter is equal to the water-retaining capacity, and the dose is repeated after one or several days, the reduction of the dissolved organic matter is greater than before; the effluent is, however, still putrescible. If the dosing of the filter is continued, the putrescible matter in the effluent is further reduced; and when the dissolved organic matters have been reduced by 60 to 65 per cent. the effluents are non-putrescible. This stage is generally attained after the application of four or five doses, *i.e.* when the filter is only charged every third day, after two to three weeks. An increasing proportion of the organic matter is thus retained in the filter, although it was present in solution. The separate particles of sand become coated with a gelatinous film, at first very thin, but gradually increasing in thickness; and this film, on microscopical examination, is seen to contain many bacteria and other low forms of life, as well as amorphous substances which vary with the character of the sand and the sewage, but which usually contain iron. This gelatinous coating or film becomes thicker and thicker, thus diminishing the volume of the pores in the filter, but at the same time increasing the water-retaining capacity. In proportion as this film becomes thicker, the purifying action of the filter increases. The attainment is usually termed the "maturing process." A filter is considered mature when its effluents begin to contain nitric acid. The presence of nitric acid is regarded as a sign that the last stage of mineralisation and oxidation has been reached. It is assumed that the film on the filtering material has a honey-comb structure, and therefore possesses an exceedingly large surface. In the case of starch, for example, the surface of a cubic millimetre, after conversion into starch paste, has been calculated at over two million square millimetres. The film has an internal as well as an external surface, and can absorb gases in very large quantities, as well as many organic and inorganic substances, colouring matters, scented and bitter substances, resins, tannins, enzymes, and other substances of high molecular weight. In order to demonstrate the absorbent powers of this film, I have washed out small quantities from biological filters, placed the material in closed bottles provided with manometers, and admitted known volumes of absorbable gases, such as oxygen and carbon dioxide. After a very short time the manometers showed a diminution in pressure, an increasing diminution being observed as the gases were absorbed by the sludge.

If sewage, solutions of albumen, or similar liquids are poured over a mature filter, the dissolved organic solids are absorbed and retained by the above-mentioned film much more readily than by freshly ignited gravel. This increased absorptive power is also possessed by certain kinds of gravel containing large quantities of iron, such as is found on the North German Plain. After the sewage has passed through the filter, *i.e.* after a few seconds or minutes, according to the size and depth of the filtering material, the gases of the atmosphere enter the pores of the material. The retained organic matters are decomposed with the aid of micro-organisms. The absorbed oxygen is thus used up and replaced by fresh oxygen from the air in the pores. This causes a partial vacuum in the pores of the filter, and the surrounding air is drawn in with considerable energy. By means of an experiment I was able to show that the oxygen was drawn in, even through very narrow glass tubes from a closed vessel connected with the filter, with such energy as to cause a considerable diminution of pressure in the vessel. The oxygen then oxidises the organic matters which have been retained by the filter and broken down by the action of micro-organisms. The process is accompanied by the production of considerable volumes of carbon dioxide, which is partly absorbed, partly leaves the filter with the next charge of sewage, and partly escapes by gaseous diffusion. The atmosphere over a biological filter contained 0·6 per cent. of carbon dioxide, *i.e.* twenty times as much as is present in the atmosphere normally. If pure water is poured over a mature filter it is soon discharged containing considerable quantities of carbon dioxide. A second dose also contains carbon dioxide, and the process may be carried on for months without exhausting the carbon dioxide, thus showing that the organic carbon of the retained organic matter is converted into carbon dioxide. The organic nitrogen which has been absorbed is converted into nitric acid and the organic sulphur into sulphuric acid. We found, for example, in the effluent from a filter receiving a solution of albumen containing 100 parts per 100,000, on an average 6·22 parts of carbon dioxide, 4·0 parts of sulphuric acid, and 8·0 parts of nitric acid per 100,000.

The sulphuric acid in the effluent corresponds almost exactly to the organic sulphur in the solution of albumen; whilst the nitric acid only represents a little over 20 per cent. of the nitrogen in the albumen. About 58 per cent. of the total nitrogen is found in the effluent; besides the nitric acid, 10 per cent. is found as ammonia and 25 per cent. as organic nitrogen. About 42 per cent. of the nitrogen from the albumen disappears either in the gaseous form or accumulates in the humus, which is deposited in the filter. A considerable part of the carbon of the albumen also disappears as gaseous carbon dioxide, but a part also goes to form the humus which accumulates in the filter.

The formation of nitric acid is dependent upon the activity of micro-organisms, as has been shown by Schloesing and Müntz, Warington, Winogradsky, and others. How far this is also the case for the formation of carbonic and sulphuric acids has not yet been determined. If the activity of the micro-organisms is inhibited by adding disinfectants to the liquids with which the filters are charged, the formation of nitric acid ceases. The effluents are, therefore, free from nitric acid, but at first they are so far purified as to be non-putrescible. If the dosing of the filter with sterile liquids is continued, the quantity of organic matter in the effluent gradually increases, and the absorptive powers of the filter become exhausted. This state of exhaustion continues until bacteria are again introduced or until the absorbable organic matters are decomposed by ignition or some other means.

The importance of micro-organisms for the purification effected by biological filters has been demonstrated for me by Dr. Carnwath as follows:—Sterile putrescible liquids were poured over sterile filters, every care being taken to exclude bacteria. The first portions of effluent showed a certain diminution in the oxygen absorbed, but in the later portions this diminution became less, and finally zero. A second sterile filter was similarly treated, with the exception that no care was bestowed on the exclusion of bacteria derived from the atmosphere. In this filter bacteria gradually developed, and at the same time the purifying action gradually increased. Under otherwise exactly similar conditions, one filter was soon exhausted, and the other, into which bacteria from the atmosphere had been allowed to enter, was not only not exhausted but its purifying action increased.

From the above experiments it may be considered proved that satisfactory working of land filters is not possible without the aid of micro-organisms.

Similar results are produced if, instead of micro-organisms, the oxygen of the air is excluded from the filters. This is proved by allowing carbon dioxide, or better, hydrogen or nitrogen, to enter the filter when the sewage is discharged. The formation of carbon dioxide, nitric and sulphuric acids, gradually ceases in this case also, and the effluents from the filter become putrescible.

The absorptive action of the filters is therefore quickly exhausted by excluding either micro-organisms or atmospheric oxygen.

If an intermittent land filter is to work satisfactorily, the presence in the filter of micro-organisms and atmospheric oxygen is not sufficient; certain periods of rest are necessary, *i.e.* during a certain period the filter should receive no organic matter, so that the organic matters already absorbed may be decomposed and mineralised. Experiments on these phenomena have been carried out with a filter, 1 metre deep, the material of which originally had an effective size of 0·24, a uniformity coefficient of 2·2, and a water-retaining capacity of 15·5 per cent. The material was therefore approximately ideal. When the filter was dosed every third day with a quantity of sewage equal to the water-retaining capacity, the oxygen absorbed was reduced by more than 80 per cent., and the effluents contained 5 parts of nitric acid per 100,000. The total volume of the pores of the material was 37 per cent. and the water-retaining capacity 15·5 per cent. In the filter, therefore, after the discharge of the sewage, the air space was 21·5 per cent. of the total volume of the filter. Samples of air extracted from the filter at various depths, 10, 50, and 90 cm. below the surface, were analysed, with the result that, soon after charging, the oxygen present 10 cm. below the surface was 20·8 per cent.; 50 cm. below, 16·2 per cent.; and 90 cm. below, 12·5 per cent. The carbon dioxide present was 0·3 per cent. near the surface, 1·5 per cent. in the middle, and 2·0 per cent. near the bottom of the filter. After standing for a day the oxygen in the centre of the filter, and near the bottom, had been further reduced, as will be seen from the following table. On the following day the percentage of oxygen in the air at both these points began to increase, and on the third day it was present in almost the same quantities as at the beginning of the experiment. The amount of carbon dioxide in the middle and at the bottom of the filter rose within the first twenty-four hours to 5·9 and 7·6 per cent. respectively; it then began to sink, and on the third day had reached 3·2 and 4·1 per cent. respectively.

Air Analyses relating to Consumption of Oxygen and Production of Carbon Dioxide in Filters (receiving Sewage every Third Day).

Depth Sample taken (cm.)	Immediately after Charging.	After Days.		
		1	2	3
	Oxygen in Air from Filter (per cent.).			
10	20·8	20·4	20·0	20·4
50	16·2	10·8	13·0	15·7
90	12·5	9·0	12·0	13·3
	Carbon Dioxide in Air from Filter (per cent.).			
10	0·3	0·6	0·8	0·7
50	1·5	5·9	5·2	3·2
90	2·0	7·6	6·6	4·1

From such results it can be concluded that the decomposition processes are most active on the second day, and that on the following day less oxygen is consumed than can gain access to the filter from the surrounding atmosphere. These analyses do not show the whole of the oxygen which is present in the filter; that which is held absorbed by the filter films is much more important, as I shall show later, and this oxygen is not estimated in the above analyses.

The same filter was then used for several months, and charged, not every third day, but every other day, with the same quantity of sewage. The results of the analyses of the gases in the filter are given in the following table. Even at this rate of working, the oxygen consumed in the surface layers of the filter can be easily replaced. In the middle of the filter the oxygen, just after charging, amounted to 6·8 per cent.; after twenty-four hours it was still less; and on the second day it had risen to 10·4 per cent. There was a deficit of oxygen as compared with that present at the same period when the filter was charged every third day. The differences observed at the bottom of the filter were even more marked. Just after charging, the oxygen present there was only 3·6 per cent., twenty-four hours later 1·0 per cent., and on the second day 4·4 per cent. The carbon dioxide produced was, at all three points, greater than during the slower rate of working. On the second day, *i.e.* when the next charge was due, the carbon dioxide in the air at the bottom of the filter amounted to 8·8 per cent.

AIR ANALYSES RELATING TO CONSUMPTION OF OXYGEN AND PRODUCTION OF CARBON DIOXIDE IN FILTERS (RECEIVING SEWAGE EVERY OTHER DAY).

Depth Sample taken (cm.)	Immediately after Charging.	After Days.	
		1	2
	Oxygen in Air from Filter (per cent.).		
10	20·8	17·2	18·4
50	6·8	5·9	10·4
90	3·6	1·0	4·4
	Carbon Dioxide in Air from Filter (per cent.).		
10	0·6	1·6	1·6
50	5·4	7·8	6·6
90	5·2	8·2	8·8

The same filter was next charged every day for several months with the same quantity of sewage. Soon after charging, the oxygen in the air at the bottom of the filter was 0·1 per cent., as against 12·5 per cent. during the period of slow working. Twenty-four hours later, when the next charge was due, the amount of oxygen was still 0·1 per cent. At the same time there was no increase in the amount of carbon dioxide at the bottom of the filter, as will be seen from the following table. This shows that the large quantities of carbon dioxide found during the period of charging every other day were really due to increased production and not to an accumulation of carbon dioxide in the filter.

AIR ANALYSES RELATING TO CONSUMPTION OF OXYGEN AND PRODUCTION OF CARBON DIOXIDE IN FILTERS (RECEIVING SEWAGE EVERY DAY).

Depth Sample taken (cm.)	Immediately after Charging.	3 Hours later.	24 Hours later.
Oxygen in Air from Filter (per cent.).			
10	16·8	11·7	16·5
50	11·3	8·8	10·9
90	0·1	0·8	0·1
Carbon Dioxide in Air from Filter (per cent.).			
10	3·2	5·1	3·4
50	4·2	5·4	4·6
90	4·4	4·4	4·5

When charged every day, the effluent from the filter did not contain any nitric acid; whilst, when charged every other day, 3·0 to 4·0 parts per 100,000 were obtained, as against 5·0 parts when the filter was charged every third day.

It is remarkable that, in spite of the high rate at which this filter was operated, the effluents were always satisfactory and non-putrescible. The reduction effected in the oxygen absorbed was, up to the end of the experiments, about 70 per cent. After the filter had been receiving a layer of sewage 24 cm. deep daily for three months it became impermeable. On standing for several weeks it had so far recovered as to be able to deal satisfactorily with the original volume of sewage applied every third day. In all these experiments fresh crude sewage was employed, corresponding in composition to ordinary town sewage; before being used on the filters it had only passed through a detritus tank.

The oxygen found in the air from the interstices of the filter is not, as was stated above, the total oxygen in the filter. If a mature filter is placed in a closed vessel connected with a gas-holder containing air or oxygen, oxygen is rapidly drawn into the filter, as in the case of the sludge adhering to the filtering material. This oxygen is chiefly absorbed, and is hence not found in the air of the filter. An overworked filter which has become black, by the deposition of sulphide of iron, turns brown when the oxygen of the air is admitted to oxidise the sulphide of iron. In a similar manner other oxidisable substances are altered. Oxygen is, moreover, accumulated within the filter on the surface films by absorption, and this absorption process seems to be a necessary part of biological purification. The following experiments carried out under my supervision support this view. A mature filter was filled with sewage so as to entirely fill the pores of the filter; this was accomplished by closing the outlet. Air, and later oxygen, was blown into the filter from the bottom; but even after some days the sewage could not be converted into a non-putrescible liquid. The oxygen which is introduced into a filter, the pores of which are full of liquid, cannot be absorbed as in the case of a filter which only contains liquid to the extent of its water-retaining capacity. The free unabsorbed oxygen cannot carry out the necessary oxidising action. The result of this experiment appears to me to afford an explanation of the energetic oxidising action which the oxygen of the air exhibits in biological filters. We cannot regard the oxygen as being present in the ordinary molecular state, but must assume that it is ozonised by the high pressures existing in the gelatinous film, and is thus rendered extremely active.

The increase in the purifying action of a mature filter is not to be explained entirely by the increase in surface attraction ; it is also due in part to a direct suction (resorption) on the part of the gelatinous film which covers the filtering material and which has been formed by plants and animals. Only in this manner is it possible to explain the fact that a mature filter retains sugar, urea, and other non-absorbable substances, so that these do not appear in the effluents from land filters. These actions were investigated by me a few years ago in the effluent from a sugar factory and later in the sugar-containing effluent from a dairy. Since then Dziergowski has published the results of some important experiments in this direction.

Balancing of Materials supplied to and Products obtained from Filters.—The above details would be incomplete without an attempt to show definitely how the substances entering the filter are disposed of. For some substances this is easy. If, for example, a solution of pure albumen is treated on a filter, the sulphuric acid in the effluent corresponds almost quantitatively to the amount of organic sulphur in the albumen solution. The problem is more difficult for the main constituents of the organic matter, for the nitrogen and the carbon. The carbon dioxide formed partly diffuses into the air and is partly retained by the filter; indeed, so tenaciously that a very prolonged washing is necessary to remove it. A part of the carbon remains in the filter in the form of very stable organic matter, as has been shown by the Massachusetts experiments, and another portion leaves the filter with the effluent. In the case of the nitrogen, the problem is equally complicated ; to a certain extent more so, for the nitrogen escapes partly in the elementary state, partly as ammonia, and partly as nitric acid. A balance sheet of the nitrogen entering and leaving a filter can therefore only be furnished when the filter is isolated from the atmosphere. Dr. Kammann has carried out an experiment for me on this subject, but a full description would occupy too much space here. The main result of the experiment was to show that in the effluent from the filter 59·7 per cent. of the total nitrogen of the sewage was present, chiefly as ammonia, since the formation of nitric acid was not possible under the conditions of the experiment. The nitrogen escaping in the gaseous form amounted to

22·8 per cent., and hence 17·5 per cent. must have remained in the filter.

In Massachusetts the effluents from No. 1 Filter contained 69·3 per cent. of the total nitrogen applied. Within the filter 3·8 per cent. was found remaining, and it was assumed that 26·9 per cent. had escaped in the gaseous form. These figures agree fairly well with those given above.

In land filtration the presence of nitric acid in the effluent is regarded as a very useful index of the condition of the filters. Carbon dioxide and sulphuric acid might also be used in this connection, but nitric acid furnishes a more delicate index; first, because it is generally absent from the crude sewage; and secondly, because it is easily reduced, and therefore furnishes an indication of any deficiency of oxygen. The formation of nitric acid is apparently entirely dependent upon the action of micro-organisms. Experiments which I have had performed on the direct oxidation of nitrogenous bodies have not yielded any results comparable with the very active oxidation which takes place in biological filters, and hence they support the opinion which is generally held on this matter. We have discovered, however, contrary to what is generally maintained, that not only are the Winogradsky bacteria concerned, but that nitrifying organisms also exist which transform organic nitrogen directly into nitric acid, without the intermediate production of ammonia. These organisms form nitrites and nitrates simultaneously. Similar results have been obtained by other observers, and hence a full description of the experiments is unnecessary.

The following experiment was undertaken to determine in what part of the filter the nitric acid is formed. A mature filter, 1 metre deep, was dosed with distilled water until the effluent was free from nitric acid. Successive layers of the filter, 10 cm. deep, were then removed, and the freshly formed nitric acid was washed out and determined. The results are given in the following table:—

FORMATION OF NITRIC ACID IN LAND FILTERS.

Depth in cm.	Nitric Acid (parts per 100,000 of soil).	Depth in cm.	Nitric Acid (parts per 100,000 of soil).
10	39·2	60	31·2
20	40·8	70	28·4
30	36·4	80	12·4
40	30·4	90	12·8
50	26·0		

It will be seen that the formation of nitric acid diminishes gradually to a depth of 70 cm., and then suddenly in the lower layers, without, however, completely ceasing.

Land Filtration.—In land filtration, as we have already seen, a layer of very stable humus is formed on the particles of sand, and this layer increases with time, so as to diminish the size of the pores of the filter. The water-retaining capacity of the filter is increased by this layer, but the aeration is diminished, and the sewage has greater difficulty in getting away. The main portion of the deposit occurs, however, with suitable material, near the surface, in the upper six inches. Above I expressed the opinion that the renewal of this layer, either by removal and replacing with fresh material or by washing, appeared to be within the bounds of practical consideration.

In Massachusetts extended experiments have been carried out, to see if the action of the filters can be increased by a preliminary removal of the suspended matters from the sewage. This preliminary treatment was carried out (1) by settlement, (2) by chemical precipitation, (3) by septic treatment, and (4) by treatment in coarse coke straining filters, the action of which was supposed to be comparable to that of a sieve, but which ought to be regarded as artificial biological filters. The conclusion was reached that the removal of suspended matters is advisable in all cases, but that the use of chemicals for this purpose is attended with so much expense and other difficulties that, when compared with the increased action of the filters thus obtained, their use is not advisable. The best results were, however, obtained with sulphate of alumina. In England, chemical treatment as a preliminary to land filtration was recommended by Sir E. Frankland. According to the evidence given before the present Royal Commission, the opinion seems to prevail that by preliminary chemical treatment the quantitative action of land filters can be doubled.

Preliminary treatment on artificial biological filters will be dealt with in the following section (p. 153). This was the most satisfactory method investigated in Massachusetts.

Preliminary treatment by means of septic tanks does not appear to have created a good impression; but in the Western States of North America, Saratoga, Lake Forest, Wauwatosa, etc., better results have been obtained than in Massachusetts. Experiments in this direction as regards land filtration do not appear to have been carried out in England, but, in connection with irrigation farms, very satisfactory results have been obtained by preliminary treatment in septic tanks (Birmingham).

For over a year I have had various land filters under observation; some of these have received, for purposes of comparison, fresh sewage and some septicised sewage. I have come to the conclusion that the septic treatment considerably relieves the filters, on account of the removal of suspended solids. This relief more than counterbalances the disadvantages of the septic action, which are largely due to the tank effluent containing sulphide of iron in such a fine state of subdivision that it penetrates to a considerable depth in the filters. A clogging of the filters from this cause has, however, not yet been noticed. One of these filters, two metres deep, was constructed of sand, which originally had an effective size of 0·3 and a uniformity coefficient of 1·6, the water-retaining capacity of the filter being

21·8 per cent. of the total volume. For two months the filter was charged every other day with a layer of sewage 15 cm. deep, *i.e.* at the rate of 7·5 cm. per day, or over 60,000 gallons per acre per day. During the following month the charge was 30 cm. every other day, and for the next two months the charge was alternately 30 cm., 30 cm., and 60 cm. every other day. This variation in the rate of feeding was purposely adopted in order to represent conditions such as may occur in actual practice, where a filter may have to deal at times with quantities of sewage in excess of the water-retaining capacity. The filter bore this treatment very satisfactorily. The reduction in the oxygen absorbed was between 60 and 80, and generally over 70 per cent.; the nitric acid in the effluent amounted to 7·5 parts per 100,000. The filter was next charged for two months every other day with 30 cm. and 60 cm. of sewage alternately. This treatment was also borne satisfactorily, the reduction in the oxygen absorbed being between 70 and 80 per cent., and the nitric acid in the effluent between 5·0 and 10·0 parts per 100,000. The sewage also passed through the filter at the same rate as previously. If we compare these results with those given on p. 148, they are certainly to the advantage of septicised sewage. Further experiments are in progress, which will afford increased material for such a comparison.

The amount of sewage which this filter is now treating is equivalent to about 180,000 gallons per acre per day; whereas, by irrigation, 6000 to 7000 gallons is the maximum quantity which can be dealt with. (Brunswick 2200, Berlin about 3100, Freiburg about 5000, and Breslau about 6000 gallons.)

As regards the degree of purification which can be effected by land filtration, little can be added to what has already been said. Physically and chemically the effluents from carefully constructed and well-managed land filtration works are quite equal to those which can be obtained from irrigation farms under the most favourable conditions. This method, like all methods of sewage purification, is largely dependent upon local circumstances, and hence these have to be considered in each individual case. I believe we already know sufficient to be able to predict whether and how suitable a certain soil will be for land filtration, and at what rate it will deal with sewage so as to yield a non-putrescible effluent; or, still further, one which is clear and colourless and as free as possible from pathogenic organisms. With regard to the last point it may be mentioned that the purification of sewage in the Massachusetts filters has been carried so far that the number of germs per c.c. has at times been reduced from 4·75 millions to 58 (see Table, p. 153).

Great importance is attached, as has already been mentioned, to the presence in sewage of the coli bacillus, which is always present in very large numbers, and which possesses a great similarity to the typhoid bacillus. By carefully operating the Massachusetts filters, *Bacillus coli* has been removed from sewage to the extent of the effluent giving negative tests when 1 c.c. was examined, and only occasionally giving positive tests with 100 c.c. The results obtained show that the various filters remove 97 to 100 per cent. of the coli bacilli and about 98·2 per cent. of the total micro-organisms. As regards the removal of bacteria, I should place greater reliance on a carefully prepared and well-managed land filter than upon any irrigation area, or indeed upon any other method of sewage purification; for the artificial biological methods, to be next described, do not furnish any guarantee for the removal of pathogenic germs.

REDUCTION OF BACTERIA IN SEWAGE BY LAWRENCE FILTERS (YEARLY AVERAGE FOR 1897).

Nature of Sample.	Crude Sewage.	Effluent from Filter No. :—													
		1	2	4	5A	6	9A	10	12A*	13A*	14A*	19*	65*	80	81
Bacteria per c.c.	4,758,000	28,800	242	58	70,800	11,700	11,460	4,350	1,695	136	1,445	800	21,200	4,100	530,000
Percentage reduction . . .		99·39	99·99	99·99	98·51	99·75	99·76	99·91	99·96	99·99	99·97	99·98	93·08	99·91	88·86

* Preliminary treatment by sedimentation, precipitation, and filtration.

C. Artificial Biological Methods.

Historical.—In 1892, the Twenty-Third Report of the Massachusetts State Board of Health was published, describing experiments which had been carried out with filters during the years 1889–91. These filters were made with gravel varying from 3 to 19 mm. in size, and as much as 170,000 gallons of sewage was treated per acre per day, or, after the introduction of artificial aeration, as much as 340,000 to 420,000 gallons. These experiments were repeated in England with results which must now be considered as epoch-making, since they gave rise to the so-called artificial biological processes. I have attempted to draw a distinction between natural and artificial biological methods by restricting the use of the word artificial to such filters as were constructed not of naturally occurring soil, but which were built up artificially. If this distinction is to be maintained, we must regard the Massachusetts experiments, and even earlier English experiments, as the starting-point of the development of these methods. It appears to me, however, that a second characteristic feature should be noted. At Lawrence the material employed in the construction of the filters gradually became so coarse that the usual method of applying the sewage failed. The sewage did not distribute itself over the surface of the filter, but simply passed downwards through the large pores of the gravel without being purified. In order to obtain an even distribution, a layer of loamy soil was first placed on the surface of the coarse gravel, but this did not produce a satisfactory result. Next, an automatic syphon was constructed to discharge sewage on to the filter at regular intervals of twenty or thirty minutes, and in this manner it was possible to treat larger volumes of sewage than had hitherto been possible by biological processes. The reports on these experiments attracted the attention of Sir Alexander Binnie, at that time Chief Engineer to the London County Council, and of J. Corbett, the Borough Surveyor of Salford. The experiments which these two gentlemen commenced, independently of one another, have led to a complete revolution in the domain of sewage purification. Quite independently, Stoddart carried out a series of interesting experiments, to which I shall again refer later.

The historical course of events has been variously described from time to time. Some time afterwards Binnie declared that he had for years been seeking a more rational method of disposing of the 170 million gallons of sewage which London produces daily, and from which he obtained about two million tons of sludge per annum. The appearance of the Massachusetts Report awakened in him hopes that he might be able to achieve this object in the manner described in the Report, and he accordingly commenced the experiments, which were carried out, under his direction, by the engineer Santo Crimp and the chemist Dibdin The position of Corbett in Salford was worse than that of Binnie in London, for the Manchester Ship Canal furnished the only means of disposing of the sewage of a rapidly growing industrial population, and there was no possibility of adopting either irrigation or land filtration. Corbett intended his filters to deal with the largest possible volume of sewage, and regarded thorough aeration as a necessity. Hence, following the Massachusetts example, the outlets from his filters were left open. All his experiments were directed towards distributing the sewage over the surface of the filters in the form of a rain. He first attempted to achieve this by means of troughs placed a few feet above the surface; he also constructed filters in layers, with ventilating spaces between, so that the sewage fell from one layer to the next like a shower of rain. Gradually developing the technical details of distribution, in 1894 he tried experiments with rotating sprinklers, and in the same year adopted fixed spray jets. When Corbett's experiments with spray jets became known, most experts shook their heads and regarded these fountain-like distributors as expensive and worthless toys. At the present time some of the most experienced engineers regard Corbett's method of distribution, which has in the meantime been further perfected by others, as the best, and as the one among all the other methods which is specially suitable for adoption by large towns. It affords me great satisfaction to place Corbett's experiments in their proper light here, especially as he has been too modest to come forward with any claim to priority.

The London experiments and the technical details developing out of *these* have, during the last fifteen years, alone been in the foreground, and it has generally been assumed that the experiments conducted at the Barking works formed the basis of artificial biological methods. So long as interest was centred in the contact process, to be described later, and in so far as these experiments were a direct continuation of those of Frankland and the Massachusetts Board, this assumption is warranted. Since, however, for a considerable number of years the continuous method of working biological filters has been more and more in the foreground, it must be acknowledged that the development of technical detail is due to the interpretation which Corbett placed upon the Massachusetts experiments.

Based directly upon Frankland's experiments, and not upon those of the Massachusetts Board, Stoddart appears, as we shall see later, to have had ideas upon the subject at an earlier date, but these did not attain to the same practical importance as those of Corbett. The experiments of the latter led to the development of the continuous process, whilst the London experiments form the basis of contact methods.

Contact Beds.

Barking.—In following the practical development of artificial biological processes, it is convenient first to give a description of the London experiments. In June 1890 four wooden tanks were constructed, each having a superficial area of $\frac{1}{200}$-acre. The first of these was filled with burnt clay, the pieces being about the size of peas; the second contained stones of the same size; the third coke breeze; and the fourth was filled with sand and gravel of varying size. The fourth filter was used to give the sewage a preliminary treatment before passing it on to a polarite filter. The effluent pipes from the tanks were conducted so high that the filters could be filled to the surface with sewage and kept full whilst the sewage was flowing through. Sewage was passed through for eight hours each day, and then the effluent pipe was lowered and the filters emptied. During three months working in this manner, the filters produced a non-putrescible effluent when dosed with previously precipitated London sewage. This arrangement was at that time regarded as a direct imitation of that adopted in Massachusetts. Santo Crimp has declared that he had been considering for some time the possibility of imitating the Massachusetts method of feeding filters automatically by means of syphons on a large scale, and had come to the above described arrangement. In Massachusetts the feed was discontinued every twenty or thirty minutes, and hence the pores of the filter were never completely filled with sewage. In London, however, the filters were completely full of sewage for eight hours, and the results were by no means equal to those produced in Massachusetts. It was, however, considered quite sufficient for the requirements of London if the effluents did not putrefy nor the filters become clogged.

In November 1892 it was decided to construct a similar filter, one acre in area and filled to a depth of 3 feet with coke breeze, having a 3-inch layer of gravel on the top in order to keep the coke down. When operated in the same manner as the smaller filters, this large filter did not produce the required results. The filter soon became clogged, and after six weeks' operation the effluent was putrescible. After twelve weeks the filter would scarcely allow the sewage to pass through, although it had only received chemically precipitated sewage. Finally, the sewage stood six inches deep on the surface of the filter.

The official report by Dibdin states that it had been learnt that the filter should be worked intermittently, and should at first be worked at a slower rate than had been the case. The filter, which had been worked to death, was allowed to stand for three and a half months. After three months the putrescent odour of the filter began to disappear. From November 17, 1894, the filter was filled and allowed to stand full for two hours, after which it was emptied. In this manner excellent results were produced. The capability of the filter was so promising that Dibdin was able to recommend the town of Sutton to undertake experiments with sewage which had not previously been chemically treated.

Sutton.—Preliminary experiments with clarified sewage carried on at Sutton during 1894 had yielded results so satisfactory that Dibdin's recommendations were carried out. Biological filters were constructed of burnt clay and fed with sewage from which only the coarser suspended solids had been removed by screening. The filters were operated in the same manner as the London coke-breeze filter, by alternately filling and emptying, a method which is now known as the contact method. At Sutton 750,000 gallons of sewage were treated per acre daily by this process, so as to yield a non-putrescible effluent. The oxygen absorbed was reduced by 86·5 per cent. The effluent from this filter was submitted to a second treatment in a similarly constructed and operated filter containing coke breeze. The effluent from this second filter was clear, colourless, and without smell. It was calculated that during seventy-six days, 77 tons of sludge had been retained by the biological filter, and it was believed that this sludge would be decomposed, *i.e.* liquefied and gasified. At any rate the results were so promising that the town of Sutton abandoned the methods of chemical precipitation and irrigation and definitely adopted the new process. Similar experiments were soon commenced at Manchester, Leeds, and other English towns, with the result that the favourable observations made at London and Sutton were confirmed.

The results obtained in the English experiments were a decided advance upon those obtained in Massachusetts, so far as the quantities of sewage treated per acre were concerned. In Massachusetts the practical result of intermittent filtration had generally been the treatment of a layer of sewage 3 cm. deep daily; in the Lawrence experiments 11·6 cm. had been treated daily, or 40 cm. after preliminary chemical treatment. In Sutton a filter only 70 cm. deep had treated a layer of crude sewage 86 cm. deep daily, and had converted it into a non-putrescible effluent. Later, experiments at Leeds gave 45 cm. for crude sewage, over 80 cm. for the effluent from septic tanks, and as much as 130 cm. for chemically precipitated sewage; whilst at Manchester, after treatment in septic tanks, a layer 62·5 cm. deep was efficiently treated daily.

These results at once attracted attention in the widest circles. They were discussed not only in technical journals, but also in the daily press. In England the time was ripe for the adoption of such methods The English rivers were scarcely any better than a quarter of a century before, in spite of the steps which had been taken by the authorities. The sewage problem was at a standstill; no advance was being made with irrigation, and chemical methods had proved unsuccessful.

Naturally, the heart of every town councillor leapt with joy when he was assured by experts holding responsible positions that the sewage problem was solved; that expensive palliatives, like chemical treatment, upon which even small towns like Sutton, with 18,000 inhabitants, were spending £1000 or more annually, could be done away with; and that a method had been discovered which would cost practically nothing, the adoption of which, for even only half of the sewage in England, would mean an annual saving of at least sixty million pounds sterling.

Hamburg Experiments.—In the spring of 1897, when such wonderful news was being circulated, the Hamburg authorities had to deal with a most difficult problem in connection with sewage disposal. The large Alster Lake has a world-wide reputation for its beauty, but at this date its purity and, since it lies in the heart of the town, its very existence were threatened by settlements which were taking place with increasing rapidity in its gathering ground. These settlements were largely outside the Hamburg boundaries, in another of the Federal States, and were gradually becoming town-like in character and adopting the water-carriage system of sewerage. The authorities were sanctioning the discharge of the sewage, after simple chemical treatment, into the tributaries of the Alster. If these schemes had been carried out, Hamburg would have been forced to fill in the Alster within a few years. I cite this example, not because I consider it the most important, but in order to show that at that time there was a serious gap in the practice of sewage purification which could not be bridged, under the conditions existing in Hamburg, by the application of land filtration. A visit to various English works convinced me that sewage was being treated by the new method, at rates which up to that time had been considered quite impossible. The works I saw and the methods of operation were so very similar to those for land filtration that I inquired of the experts in charge what there was new about the method. The newspapers reported that the method was new in that the sewage was no longer allowed to flow continuously through the filter, but was fed intermittently, and that the filters were inoculated with living organisms which digested the sludge retained by the filter and thus prevented clogging, a difficulty with which earlier attempts at sewage filtration had had to fight. Of this destruction of sludge it was said: "This is secured by first putting in organisms which have the nasty taste to feed and thrive on refuse." The idea became prevalent that the filters were inoculated with bacteria which were able to consume the organic matters out of the sewage. It was assumed that this was accomplished whilst the filters were full of sewage. The object of allowing a period of rest after discharging the purified sewage was to wait "until the filth destroyers again get hungry and ready to perform their office." These sludge-consuming bacteria possessed considerable interest for me, especially as my own experiments to discover bacteria which would be able to accelerate the decomposition of organic matters in sewage had remained without result. It then appeared, however, that no more favourable results had been obtained in London from experiments carried out with this object in view. Pure cultures of bacteria were not employed, and the whole matter rested upon a theoretical assumption. The experiments were simply attempts to imitate on a larger scale those carried out at Lawrence with Filter No. 16A, using the modified method of operation above described, and also coarser filtering material of coke, clinker, and broken bricks.

Just as in Massachusetts it had been believed that the bacteria decomposed the dissolved organic matters whilst the sewage was passing through the soil, so in England it was thought that this decomposition took place whilst the sewage was standing in the filter. The coke and other materials were assumed simply to form a nidus for the bacteria, and at the same time to distribute the sewage in drops through the pores of the filter, so that each drop could be attacked by the micro-organisms. From this view arose the name of "bacteria bed" for this form of filter, and the method was termed "bacterial purification." It was assumed that the energy of the bacteria was so great as to decompose the substances to such an extent that no clogging of the filter would ever occur. In some quarters it was even asserted that sand and mineral detritus would be destroyed by the bacteria, so that even from these substances no clogging was to be feared. Such views could naturally only be regarded as exaggerations. The questions as to whether the decomposition of the organic matters occurred whilst the filters were standing full of sewage, and whether the decomposition could take place without endangering a gradual clogging of the filters, appeared, however, to be of considerable importance. We have therefore conducted a long series of experiments in order to elucidate these questions. The practical importance of contact beds has been considerably diminished by the development of percolating filters, which possess greater capabilities, but the results of the Hamburg experiments are of equal scientific and practical importance for both these methods of treatment. A short de-

BOARD OF ESTIMATE AND APPORTIONMENT

scription of these experiments therefore follows here. They were carried out during the years 1897 to 1900.

Are the Dissolved Organic Matters in Sewage Directly Attacked, Decomposed, and Mineralised during the Period when the Contact Beds are Standing Full?

If a tank filled with pieces of clinker is allowed to stand for a few hours filled with sewage to the surface of the clinker, and is then emptied, the effluent is non-putrescible and contains nitrates, even although the sewage originally run into the tank was free from nitrates. If these changes are due to a direct decomposition of the dissolved organic matters by means of micro-organisms, it should be possible to show that the decomposition takes place gradually. In order to test this, six filters were constructed of exactly similar size and of the same material, and they were charged simultaneously every day with the same sewage. The first filter was discharged after standing full for half an hour, the second after an hour, and so on. The results are shown in the following table:—

SUDDEN REDUCTION IN OXYGEN ABSORBED EFFECTED BY CONTACT BEDS.

	Time Bed standing full (hours).	Oxygen absorbed (parts per 100,000).				Percentage Reduction in Oxygen Absorbed on 6th day.
		Day.				
		1st.	2nd.	4th.	6th.	
Crude sewage (filtered)	...	9·07	12·30	9·30	11·42	...
Effluent from bed 1	0·5	5·85	4·10	4·37	3·57	68·73
,, ,, 2	1	3·52	3·67	4·07	3·15	72·43
,, ,, 3	2	3·22	3·07	2·62	2·27	80·09
,, ,, 4	4	2·87	2·77	2·47	2·00	82·49
,, ,, 5	6	...	2·92	2·32	1·85	83·81
,, ,, 6	12	2·77	1·75	1·75	1·57	86·21

The table shows clearly that the reduction in the oxygen absorbed, which may be taken as a measure of the changes which have occurred, is not so great on the first as on the following day. On the sixth day the filters were so far matured that they effected a considerable reduction in the oxygen absorbed. Even with only half an hour's contact the oxygen absorbed was reduced from 11·42 to 3·57, *i.e.* by 68·73 per cent., and the effluent was non-putrescible. By a longer contact the oxygen absorbed was further reduced, but not by any means at the same rate. The main portion of the purification had taken place, therefore, during the first half hour. The experiment was repeated, allowing the first filter to stand full of sewage for five minutes, the second for thirty minutes, and so on. The

?

filters were now more mature, and within the first five minutes the oxygen absorbed was reduced from 13·87 to 2·34, *i e.* by 83·2 per cent. The main portion of the purification had thus been achieved during the first five minutes. The separation of the putrescible matters in solution does not therefore occur gradually, as would be the case if it were due to the direct decomposing action of bacteria, but quite suddenly. This sudden reduction of the organic matters must therefore have some other cause.

The result of the following experiment also cannot be explained by the assumption of a direct bacterial decomposition of the dissolved organic matters. A clinker bed was filled with sewage, emptied after standing full for an hour, and then continuously dosed with a volume of sewage sufficient to fill the bed five times, the bed remaining full to the surface. The results are given in the following table:—

Decrease in the Purification effected by Contact Beds when worked Continuously.

		Effluent.					
	Crude Sewage.	After Standing one Hour in Bed.	After Passage of Sewage Equivalent to (Fillings)				
			1	2	3	4	5
Oxygen absorbed (parts per 100,000)	10·15	4·45	3·54	3·40	6·90	7·37	8·47
Percentage reduction	...	56·2	65·0	66·5	32·0	27·3	16·5
Odour	fæcal	musty	musty	musty	slightly fæcal	fæcal	fæcal

By remaining for one hour in the bed the sewage was converted into a non-putrescible product, smelling somewhat musty, but devoid of any fæcal odour. The same result was obtained from the second filling; the effluent was non-putrescible, although it had only been in the filter a few minutes. During the next filling the purification effected was not so great and the effluent had a slight fæcal odour. Such results cannot be explained by the assumption of a direct decomposition by means of the bacteria in the filters, but may be explained by the assumption of absorptive action. It is known that absorption is a rapid process, taking place, as in this case, within a few minutes, and being able to separate considerable quantities of dissolved organic substances from a liquid, and also that the process takes place repeatedly with the same rapidity until the absorptive powers are exhausted. These powers must then be regenerated by the action of micro-organisms, *i.e.* the retained organic matters must be decomposed and mineralised before the filter can again resume its activity.

If a solution of albumen, containing about as much organic matter as is present in ordinary domestic sewage, is placed in a sterile clinker filter, and the liquid examined every few minutes, it will be found that in this case a separation of the organic matter from the solution takes place. During the first few minutes 50 per cent. or more of the organic matter is removed, whilst later the action takes place much more slowly (see fig. 88). The same action takes place, therefore, in the absence of bacteria as occurs with sewage in biological filters.

This absorptive action may be easily demonstrated by the use of colouring matters, such as methylene blue. A deep blue solution of this colouring matter assumes a much lighter greenish colour by simply being poured through a mature clinker filter; if the solution is allowed to stand for two hours in the filter it is almost completely decolourised.

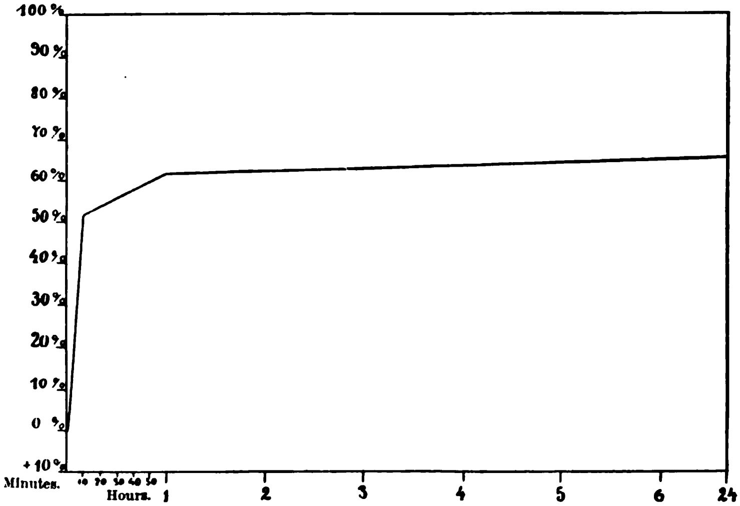


Fig. 88.—Absorption of Albumen by Sterile Clinker Filter.

If sewage is coloured with methylene blue, the blue colour disappears in a day or two, but on shaking with air the blue colour reappears, and these processes may be repeated for weeks. The solutions which have been decolourised in a clinker filter do not, however, behave in this manner; on shaking with air the blue colour is not restored, because the colouring matter has not been reduced by the action of bacteria, as in the case of sewage, but has been retained by absorption in the filter. Experiments with fuchsin, litmus, and other similar colouring matters gave exactly the same results.

By far the largest part of the purification which is effected whilst sewage is standing in a clinker filter is undoubtedly due to absorption (see p. 142). At the same time, to a certain extent, biological processes are occurring in the full filter. This may be concluded from the formation of carbon dioxide which takes place in the full filter. A sewage containing no free carbon dioxide, after being placed in a contact bed, contained 6·38 parts per 100,000, and, four and a half hours later, 11·51 parts. In order to make a closer study of this problem I had seven clinker filters prepared from a mature filter, and for a time these were dosed with sewage regularly daily. They were then thoroughly well washed out and filled with sewage. The first was discharged after five, the second after thirty minutes, the third after one hour, and so on. The results of analyses of the effluents are given in the following table:—

FORMATION OF CARBON DIOXIDE IN FULL CONTACT BEDS.

	Time of Contact.	Carbon Dioxide (parts per 100,000).			Oxygen Absorbed (parts per 100,000).	Percentage Reduction in Oxygen Absorbed.
		Combined	Free and half-combined.	Free.		
Crude sewage .	..	10·12	13·20	3·08	9·94	...
Effluent from bed 1	5 mins.	11·00	17·89	6·89	2·06	79·2
,, ,, 2	30 mins.	11·20	20·83	9·63	2·06	79·2
,, ,, 3	1 hour	11·00	21·41	10·41	2·06	79·2
,, ,, 4	2 hours	10·10	21·71	11·61	2·02	79·7
,, ,, 5	3 hours	11·22	24·35	13·13	2·00	79·9
,, ,, 6	6 hours	11·44	24·93	13·49	2·11	78·8
,, ,, 7	12 hours	11·66	27·28	15·62	2·00	79·9

From 3·08 parts per 100,000 the free carbon dioxide rose within five minutes to 6·89 parts; in twelve hours it rose to 15·62 parts in a full contact bed. The combined carbon dioxide, on the other hand, did not increase to any appreciable extent. The sudden rise at first is due to the solution of the carbon dioxide already existing in the filter. It might be assumed that the increase later was also due to this same cause, but that the carbon dioxide entered the sewage more slowly; and in experiments in which bacterial action was excluded, this gradual solution of carbon dioxide, whilst filters were standing full, has been observed, but not by any means to the same extent. We must therefore assume that in a full contact bed we have decomposition processes going on at the same time as absorption, but in the empty bed the decomposition becomes incomparably more intense.

In the above experiments it is noteworthy that again during the first five minutes the oxygen absorbed was reduced by 79·2 per cent., by an amount which was not increased by allowing the beds to stand full for a longer period; generally speaking, the effect should be greater the longer the period of action, but in this case the filters had been thoroughly washed with sewage before beginning the experiment. The above results indicate that it is not the dissolved organic matters in the liquid which are decom posed with the formation of carbon dioxide, but those which had been previously separated by absorption. For the oxygen absorbed of the liquid standing in the bed remained, after having been reduced by 79·2 per cent. during the first five minutes, practically the same for twelve hours, whereas the amount of carbon dioxide rose considerably.

In dealing with land filtration, it was shown, quite in harmony with the above view, that not the freely circulating oxygen was used up, but that which had been previously absorbed, and that no absorption of oxygen took place in the full filter.

The above experiments, together with others which need not be described here, afford a sufficient explanation of the rapid removal of putrescibility which is effected by the so-called bacterial purification. My experiments have convinced me that this initial purification is not due to bacteria, but to absorptive action. The method might therefore be more correctly termed the "absorption method," but such a name would convey a very vague idea to many. Hence, on account of the oxidation processes described in the previous section, I have recommended the term "oxidation method." Without the aid of micro-organisms, however, the process is incomplete, and is therefore on the whole biological; but to distinguish it from the two previously described biological methods, irrigation and land filtration, which may be termed "natural biological methods," because they are carried out in naturally occurring soil, we may employ the term "artificial biological methods," because they are carried out in artificially constructed filters. It is usual, however, not to apply the term biological to the processes of irrigation and land filtration, and hence, when the term "biological method" is used, it is understood to apply to this new process.

The use of the word "filter" in connection with this process is also not very suitable, because filters are generally understood to retain undissolved solids mechanically. This action has a certain importance in the application of biological methods, but the main importance is attached to the separation of the dissolved organic matters. The manner of applying biological methods just described was first termed "intermittent," then "contact process," and more recently other names have been employed. Having regard to the further development of biological methods of sewage purification, it is advisable to use the term "contact process," in order to indicate that the sewage remains for some time in contact with the filtering material, which is not the case in other more recently developed biological methods. In the contact process the filters are termed "contact beds."

As a result of the above experiments, we may state that by far the largest portion of the dissolved organic matters in the sewage has been first deposited on the surface of the clinker and retained there; and that whilst the bed remains full of sewage, decomposition occurs only to a slight extent, apparently not a decomposition of the substances remaining in solution, but of those previously absorbed. Since the absorptive powers of the beds become exhausted after repeated fillings, a sustained activity is only possible if the beds are given an opportunity to regenerate these powers whilst standing empty.

It might therefore, *a priori*, have been assumed that the period of standing empty, the aeration period, was the most important from a biological standpoint. It was therefore a question of how best to obtain an insight into these phenomena.

Importance of Oxygen.—Agricultural chemists are accustomed to measure the amount of decomposition taking place in soil by the intensity of production of carbon dioxide. Wollny was able to show that the production of carbon dioxide increased in proportion to the amount of organic matter added to the soil; but that, as soon as a certain amount of carbon dioxide had accumulated in the soil, further decomposition ceased. Wollny states that this was not due to want of oxygen, for he calculated that, after subtracting the volume of carbon dioxide produced, a sufficient quantity of air was always present in his apparatus during the experiments. He therefore attributes the ceasing of decomposition to an inhibitive action of the carbon dioxide on the micro-organisms. The following experiments make it extremely probable, however, that Wollny's observations were due to exhaustion of the oxygen present, and show that in experiments of this kind actual determinations must be made both of the oxygen present and of the carbon dioxide produced.

I have had contact beds of clinker prepared in tubulated bottles of five litres capacity, and these have been charged once a day with sewage which was allowed to remain in the beds for four hours. As the sewage was discharged, air containing 20·7 per cent. of oxygen and no carbon dioxide was led into the filters. The inlets and outlets were then closed and the filters allowed to stand empty for six hours. Samples of gas from the bottles were then examined, and found to contain no oxygen, although, after subtracting the volume of carbon dioxide produced, it would appear that a considerable volume of air still remained. The gas contained 6·4 to 9·1 per cent. of free carbon dioxide, and in some experiments—in which the atmospheric air led into the bottles was replaced by oxygen—as much as 35 per cent., *i.e.* much more than Wollny found in his experiments.

The carbon dioxide in the gases from the filters cannot be regarded as a direct measure of the decomposition taking place for another reason. The author has had constructed two contact beds in bottles, as before, one containing coke and the other gravel, each of 3 to 5 mm. size. Both were charged with the same sewage, and emptied after standing full for four hours, air free from carbon dioxide and containing 20·7 per cent. of oxygen being introduced to take the place of the discharged sewage. After standing closed for forty-four hours, samples of gas were withdrawn from the bottles and examined. In the coke bed the gas contained no oxygen and 3·2 per cent. of carbon dioxide; in the gravel bed the oxygen present in the gas was 3·3 per cent. and the carbon dioxide 8·9 per cent. In the coke bed as much and even more carbon dioxide had been formed as in the gravel bed, but it had been absorbed by the coke and retained, whereas it had been more easily liberated from the gravel.

An estimate of the intensity of the decomposition taking place, based upon the amount of oxygen consumed, appears from the above only to be reliable in cases where it can be assured that the oxygen consumed has not been retained by absorption. In order to obtain information on this point, I have had contact beds prepared in five-litre bottles, as before, constructed of freshly ignited coke and clinker 3 to 5 mm. in size. These beds were charged with distilled water and allowed to remain full for two hours. At the end of that period they were emptied, air free from carbon dioxide, as before, being led in. After standing closed for eighteen and twenty hours, the oxygen remaining in the air in the beds was 18·2 to 19·0 per cent. The oxygen retained, therefore, by absorption was very small. On repeatedly filling and emptying the beds, the same results were obtained, Hence, simple absorption may account for about 2·5 per cent. of the oxygen which is added to the filter, quite apart from that which is accounted for by biological action. When now, instead of freshly ignited clinker, material from a mature biological filter was employed in experiments exactly similar to those above described, the whole of the oxygen disappeared in fourteen and a half hours, even in cases in which water and not sewage had been used to fill the beds. Even when the bed had been charged daily for a week with distilled water, and discharged each time by the introduction of air free from carbon dioxide, the air in the bottle, after standing closed for thirteen hours, contained 2·6 per cent. of oxygen. After the experiment with distilled water had been continued for a month, the oxygen in the air admitted to the bed was reduced by 46 per cent. Throughout this period the production of carbon dioxide corresponded to the consumption of oxygen. Even after all the oxygen existing in the gases of the beds had been consumed, the production of carbon dioxide continued, at the expense of the oxygen which had been absorbed by the material of the bed.

In the above experiments nitric acid was not found in the effluents so long as the beds were charged with sewage. Even when distilled water was used, oxygen was not present at first in sufficient quantity; but after some time, when a large amount of free oxygen remained in the beds, nitric acid was found in the effluents in increasing quantities.

During the period of standing closed, the consumption of oxygen caused a considerable vacuum in the bottles, depending upon the intensity of the oxygen consumption. In freshly prepared beds it amounted to 60 or 90 c.c., and in older beds to as much as 220 c.c.

From the above preliminary experiments, it is evident, as was to be expected, that the period of aeration is of extreme importance. If a contact bed contained in a bottle is daily charged with sewage, and then allowed to stand empty in the closed bottle for six hours, the oxygen in the bottle is used up with the formation of carbon dioxide, which is found in the bed to the extent of 8 or 9 per cent. The following table shows the result of such an experiment:—

Production of Carbon Dioxide in a Mature Contact Bed charged with Sewage Daily.

Time Sewage in Contact (hrs.).	Time Bed standing empty before Analysis (hrs.).	Oxygen remaining (per cent. of total Gases).	Oxygen consumed (per cent. of Oxygen added).	Carbon Dioxide produced (per cent. of total Gases).
2	3·5	8·2	60·4	4·1
2	4	8·2	60·4	6·3
2	6	trace	circa 100	9·7
2	9	0	100	8·6
2	14·5	0	100	8·9
4	15·5	0	100	8·0
4	20	0	100	7·4
2	40·5	0	100	8·9

When we compare the results of this experiment with those given above, we see that the amount of oxygen consumed depends upon the amount of decomposable substances present in the bed. The amount of oxygen consumed therefore affords us a measure of the energy of the decomposition processes taking place in contact beds. Under certain circumstances it affords us a more reliable measure than the amount of carbon dioxide produced, but it is always advisable to determine both factors.

In the above experiments the possibility of a further quantity of oxygen getting into the beds was rigidly excluded. Under such circumstances the extension of the period of resting beyond six hours appears to be useless. In practice, however, the entrance of atmospheric oxygen into the beds is not restricted, as in the above experiments, where the formation of a considerable vacuum indicated that air would be drawn into the beds with great energy. When a twelve-litre bottle containing a reserve of air was attached, by means of a narrow glass tube, to the contact beds contained in bottles, 348 c.c. of oxygen had been abstracted from this bottle during twenty-two hours standing. At the end of this period oxygen could not be detected in the gases present in the contact bed. The bed had drawn on the reserve of air for a larger volume of oxygen, and had actually used up more than was originally present in the bed. From one of these experimental beds the sewage was discharged, and, instead of atmospheric air, pure oxygen was admitted to take its place. At the end of 144 hours this oxygen had completely disappeared, and the gases remaining in the bed contained 35·3 per cent. of carbon dioxide. When bottles containing air were attached to these contact beds, nitric acid was *present in the* effluents; but when the reserve of air was omitted, nitric acid was always absent. The nitrifying organisms had therefore been present in the beds during the months of experiment without being able to indicate their activity by the presence of nitric acid in the effluents. They had exercised an oxidising action, but the nitric acid which they formed had been immediately reduced owing to the insufficient aeration.

This experiment proves beyond doubt that a contact bed freely exposed to the atmosphere not only consumes the oxygen present in its pores during the period of standing empty, but attracts oxygen from outside with considerable energy. It might therefore be considered whether it would not be advisable to assist this process artificially.

Lowcock and Waring have made recommendations in this direction. These recommendations have not been successfully carried out in practice, on account of the high cost and the difficulty of evenly distributing the introduced air throughout the contact beds. For contact beds, as above described, artificial aeration does not appear to me to be necessary. Its adoption might be considered in connection with very fine or very deep beds, especially if these are placed in buildings which are not naturally well ventilated.

After being in operation for some time, sufficient decomposable organic matter collects in contact beds to afford material for decomposition and oxidation processes to continue for weeks. If a contact bed which has been in operation is allowed to stand for some time without being charged, the oxidation processes become so intensive that the lower layers of the bed feel quite warm. We have measured as much as 9° or 10° C. rise of temperature in such beds. These facts alone are sufficient to show the practical importance of what has been said above.

It is also evident that the time the filters are standing empty does not merely serve to introduce the air which the outflowing sewage draws in. Such was assumed to be the case by those who favoured the bacterial view. It is almost exclusively whilst the filters are standing empty, as we have seen and shall see further later, that actions occur which must be regarded as absolutely necessary for biological purification. In land filtration the period of aeration extends over the whole period of working, with the exception of the few minutes during which the sewage is passing into the filters. In the contact process biological action is suspended by keeping the beds full of sewage. This act is injurious to the biological processes. If sewage is allowed to stand longer than six hours in a mature contact bed, signs of undesirable reduction processes begin to show themselves. The effluent is then, under certain circumstances, coloured by sulphide of iron and begins to smell of sulphuretted hydrogen. Similar observations may be made with contact beds which are too deep in proportion to the size of material of which they are constructed, if, *e.g.*, they are about 6 feet deep and constructed of material $\frac{1}{8}$-inch to $\frac{1}{2}$-inch in size. Properly constructed contact beds are more adapted for thorough aeration, after the sewage is discharged, than is the soil in land filtration. In the soil it is only by overcoming considerable frictional resistance that atmospheric oxygen can find its way to depths of 18 inches or 2 feet; whereas in contact beds diffusion takes place most readily, especially if care is taken that the surface of the bed and the pores do not become clogged. It is entirely erroneous to suppose that the oxygen in the air which is drawn into the bed by the outflowing sewage is sufficient for the process. During the whole period of aeration, oxygen is being continually drawn in from the surroundings, and carbon dioxide is being expired by the bed.

If we now ask ourselves whether it can be regarded as certain that the above-described phenomena are due to biological action, we must reply that nitrification is now generally regarded as due to the action of micro-organisms; and that if a well-matured contact bed is chloroformed, the most intense nitrification is at once stopped, but the consumption of oxygen and the production of carbon dioxide continue. The higher forms of life present in our contact beds were very sensitive to the action of chloroform; they were killed by even very small doses; likewise the non-sporing bacteria, but the sporing forms were not killed. Much development of gas cannot, however, be expected from spores. Mercuric chloride produced the same results as chloroform. But, in spite of this, contact beds which were under the influence of disinfectants, and in which all signs of vital activity were absent, showed a considerable consumption of oxygen with production of carbon dioxide. The results obtained are shown in the following table:—

CONSUMPTION OF OXYGEN AND PRODUCTION OF CARBON DIOXIDE IN CONTACT BEDS UNDER THE INFLUENCE OF DISINFECTANTS.

	State of Contact Bed.	Day of Experiment.		
		1st.	2nd.	3rd.
Oxygen consumed (per cent. of oxygen admitted)	mature	30·4	6·3	11·1
	fresh	10·6	13·0	9·2
Production of carbon dioxide (per cent. of air in bed)	mature	3·1	2·6	1·1
	fresh	0	0	0
Percentage reduction of oxygen absorbed	mature	81·8	73·7	...
	fresh	64·0	65·9	...

All signs of vital activity were destroyed by mercuric chloride (1 in 1000). The large reduction in the oxygen absorbed from permanganate of potash is due to the absorptive action of the films on the surface of the material of the contact bed. The fact that on the first day of experiment one-third of the oxygen admitted to the beds was used up is also due to the same absorptive action, but on the second and third day the amount of this action sank to a point which was the same as in freshly prepared beds. On the first day of experiment the amount of carbon dioxide found in the gases from the bed was 3·1 per cent., on the second day 2·6, and on the third day 1·1 per cent.; whereas freshly prepared beds contained no carbon dioxide under the same conditions. This production of carbon dioxide must therefore be due to chemical and physical causes. It is possible that this decomposition is due to enzymes, which, as we have seen, are present in the film covering the material of the filter, which film also contains unstable organic matter. A direct chemical liberation of carbon dioxide could not be assumed in this case, as in another experiment in which the sewage was sterilised by means of 0·5 per cent. of sulphuric acid. In this latter experiment the carbon dioxide found on the first day was 19·5 per cent., on the second day 16·7, and on the third day 9·1 per cent.

It has already been shown that before oxygen can be active it must first be absorbed in the contact bed. The action of the micro-organisms causes a deficit of this absorbed oxygen, which must be made up by the introduction of more oxygen, and this introduction can take place even after biological action has been excluded.

From the above facts it is clear that contact beds may be filled, if necessary, several times in succession without intermediate aeration, and yet yield a non-putrescible effluent. Our experiments also show that this possibility should only be utilised in urgent cases, or else too much undecomposed organic matter will accumulate in the beds. Such accumulations automatically increase the intensity of the processes of absorption, decomposition, and oxidation, but not sufficiently to obliterate the results of overworking. Hence, temporary excessive working of contact beds should be followed by longer periods of rest. This should also be the case because the accumulation of carbon dioxide in the beds tends to promote the weathering of the material.

Besides explaining the importance of aeration, the above experiments furnish information upon another question. They give some ideas upon the selection of material for constructing biological filters. In the first place, we require a maximum development of absorptive powers, and, in the second place, the material should be able to resist weathering processes. The organic matters in sewage are possessed of very large absorptive powers, and hence it might be thought that all material would be equally suitable for the construction of biological filters, after becoming sludged up to a certain extent. With certain material, however, as we shall see later, the filter has scarcely become mature before it clogs up, and hence it is necessary to find a material which is satisfactory both qualitatively and quantitatively.

Importance of Surface Extent.—Absorptive forces are dependent upon the amount of surface exposed, and the finer the material the larger is the surface. The size of the material must therefore exert an influence upon the action of biological filters. Experiments on this point have been carried out by me both in enclosed filters—because considerable value attaches to the determination of the changes occurring in the air of the filters—and in open filters constructed of the same material, allowing of free entrance of the atmosphere. Comparisons were made between coke and gravel from the Elbe, *i.e.* a clean rounded gravel. The material was sieved into sizes from 2 to 3 mm. to 10 to 20 mm., as shown in the following table. Contact beds were constructed of the various sizes of material, and filled daily with the same sewage. The beds were allowed to stand full for four hours and then left to aerate for twenty hours, again filled, and so on. The analytical results of determinations of the gaseous oxygen consumed, the carbon dioxide produced, and the reduction in the oxygen absorbed from permanganate of potash by the effluent, are shown in the table. The analyses were performed on the second and ninth days.

EFFECT OF SIZE OF MATERIAL. EXPERIMENTS WITH ELBE GRAVEL.

Size of Material.	Oxygen Absorbed (parts per 100,000).	Percentage Reduction in Oxygen Absorbed.	Oxygen Consumed. Per cent. of Oxygen admitted to Bed.	Carbon Dioxide produced. Per cent. of Air in Bed.
2-11-1899.—Beds four hours full, twenty hours empty. (Filters enclosed during period of aeration.)				
Crude sewage	12·47	...	...	...
Effluent from gravel, 2–3 mm.	5·88	52·8	62·3	5·2
,, ,, 3–5 ,,	6·04	51·6	46·4	3·9
,, ,, 5–7 ,,	6·43	48·5	32·4	2·6
,, ,, 7–10 ,,	6·56	47·6	35·7	3·3
,, ,, 10–20 ,,	6·89	44·7	30·0	3·1
9-11-1899.—Beds four hours full, twenty hours empty. (Filters enclosed during period of aeration.)				
Crude sewage	10·94	...	...	...
Effluent from gravel, 2–3 mm.	4·97	54·5	94·7	10·3
,, ,, 3–5 ,,	5·43	50·4	80·7	9·0
,, ,, 5–7 ,,	5·62	48·6	65·2	7·2
,, ,, 7–10 ,,	5·96	45·5	64·7	7·3
,, ,, 10–20 ,,	6·32	42·2	63·8	8·6

The finer the material the greater is the reduction in the oxygen absorbed; at the beginning of the experiments the reduction was 52·8 per cent. with the finest material (2 to 3 mm.) and 44·7 per cent. with the coarsest material (10 to 20 mm.). Correspondingly the oxygen used up from the air of the beds was larger in amount in the fine beds than in the coarse. In the finest beds it was 62·3 per cent. of the oxygen admitted into the beds and in the coarsest 30·0 per cent. After working for nine days the values were 94·7 per cent. for the finest beds and 63·8 for the coarsest. The figures representing the production of carbon dioxide show exactly the same variations.

In the next table the corresponding results with the coke beds are recorded. The experiments were carried out at the same time and with the same sewage as those with the gravel beds. At the beginning of the experiments the reduction in the oxygen absorbed by the effluent from the finest bed was 67·7 per cent. and from the coarsest bed 48·6 per cent. Nine days later the results were practically the same, due to the insufficient supply of oxygen, as will be seen from the results obtained with open beds (p. 172).

EFFECT OF SIZE OF MATERIAL. EXPERIMENTS WITH COKE.

Size of Material.	Oxygen Absorbed (parts per 100,000.)	Percentage Reduction in Oxygen Absorbed.	Oxygen Consumed. Per cent. of Oxygen admitted to Bed.	Carbon Dioxide produced. Per cent. of Air in Bed.
2-11-1899.—Beds four hours full, twenty hours empty. (Filters enclosed during period of aeration.)				
Crude sewage	12·47	...	...	...
Effluent from coke, 2-3 mm. .	4·03	67·7	74·4	3·7
,, ,, 3-5 ,, .	4·96	60·1	57·0	2·1
,, ,, 5-7 ,, .	5·11	59·0	52·2	1·6
,, ,, 7-10 ,, .	5·11	59·0	45·9	1·6
,, ,, 10-20 ,, .	6·43	48·6	42·0	2·2
9-11-1899.—Beds four hours full, twenty hours empty. (Filters enclosed during period of aeration.)				
Crude sewage	10·94	...	..	...
Effluent from coke, 2-3 mm. .	3·76	65·6	100·0	6·9
,, ,, 3-5 ,, .	4·67	57·8	84·1	5·4
,, ,, 5-7 ,, .	4·75	56·6	71·0	4·9
,, ,, 7-10 ,, .	5·35	51·0	61·8	5·1
,, ,, 10-20 ,, .	5·35	51·0	59·9	5·0

The consumption of oxygen at the beginning was 74·4 per cent. in the finest beds and 42·0 per cent. in the coarsest; higher in both cases than with gravel beds. Carbon dioxide was not present in quantities as large as with gravel beds, because coke absorbs this gas and retains it more than fresh gravel. After nine days' working, the finest bed consumed 100 per cent. of the oxygen admitted into the bed and the coarsest 59·9 per cent.

From the above we see that the decomposition process, as well as absorptive action, is more intense in fine material than in coarse, and more pronounced in coke beds than in beds constructed of gravel.

The results obtained by the use of beds freely exposed to the atmosphere, and dealing with the same sewage as the enclosed beds, are given in the following table. The finest coke reduced the oxygen absorbed by 70·2 per cent., the coarsest by 51·0 per cent.; the finest gravel gave a reduction of 61·8 per cent., the coarsest 46·5 per cent.

That better results are produced with coke than with gravel beds had already been established by practical working. This is generally attributed to the fact that coke is more porous than gravel. The numerous cavities and pores in coke presenting a large surface are supposed to furnish favourable points to which the micro-organisms can become attached, and to prevent them being washed away. They are also supposed to retain air

Effect of Size of Material. Experiments in Coke and Gravel Beds. (Freely exposed to the atmosphere.) The crude sewage had an oxygen absorbed of 10·94 parts per 100,000.

Nature and Size of Material.	Percentage Reduction in Oxygen Absorbed.	
	Exposed Beds.	Enclosed Beds.
Coke, 2–3 mm.	70·2	65·6
,, 3–5 ,,	69·0	57·8
,, 5–7 ,,	64·6	56·6
,, 7–10 ,,	62·5	51·0
,, 10–20 ,,	51·0	51·0
Gravel, 2–3 mm.	61·8	54·5
,, 3–5 ,,	61·8	50·4
,, 5–7 ,,	57·0	48·6
,, 7–10 ,,	56·6	45·5
,, 10–20 ,,	46·5	42·2

for purposes of aeration. The following experiment was undertaken to determine whether these assumptions are correct.

Contact beds were constructed of pumice-stone and fresh clinker graded to the same size. Pumice-stone is more porous than clinker, but the results given in the following table show that by the fourth day of experiment the clinker reduced the oxygen absorbed more than the pumice-stone and that the clinker maintained this superiority throughout the experiment. On the twelfth day the pumice-stone reduced the oxygen absorbed by 30·7 per cent. and the clinker by 47·8 per cent.; at the fiftieth filling the pumice-stone effected a reduction of 63·0 per cent. and the clinker 77·7 per cent. This shows that the importance of porosity in the material has been overestimated.

Comparison of Results produced by Contact Beds of Pumice-stone and Clinker.

(Size of material same in each case.)

No. of Filling.	Oxygen Absorbed (parts per 100,000).			Percentage Reduction in Oxygen Absorbed.	
	Crude Sewage.	Effluent from Pumice-stone.	Effluent from Clinker.	Effluent from Pumice-stone.	Effluent from Clinker.
1	6·80	5·57	5·82	18·0	14·3
4	6·92	5·37	4·77	22·4	31·0
12	7·00	4·85	3·65	30·7	47·8
16	5·15	2·72	1·70	47·0	67·0
23	7·97	3·35	1·95	58·0	75·5
34	8·22	4·52	2·20	45·0	73·2
50	10·20	3·77	2·22	63·0	77·7

It therefore remained to determine whether the chemical composition of the material is of importance. All the samples of coke and clinker which we have employed have contained considerable amounts of iron. When our contact beds were charged with sewage at a comparatively high rate, and aeration was retarded, the effluents contained as much as 4·0 parts of iron per 100,000, although the sewage contained less than 0·1 part per 100,000. When worked normally, iron was absent in the effluents or only present in traces. The power which iron is known to possess of combining with oxygen, and then giving up this oxygen to reducing substances, made it probable that iron plays an important part in the composition of material for contact beds. The following experiment was undertaken to obtain information on this point:

Two contact beds were prepared of Elbe gravel, 5 to 7 mm. in size, and in one small wrought-iron nails were evenly distributed throughout the material; no such addition was made to the other. Both beds were daily charged with the same sewage. The gravel in the bed containing the nails gradually lost its white or yellowish appearance, and became coated with an even brown layer of ferric hydroxide. A coke bed, and a gravel bed to which limestone in the form of oyster shells had been added, were operated in the same manner as the other gravel beds, and the results obtained are shown in the following table:—

EFFECT OF IRON AND LIMESTONE ON CONTACT BEDS.

Nature of Sample.	Oxygen Absorbed (parts per 100,000).	Percentage Reduction in Oxygen Absorbed.	Oxygen Consumed. Per cent. of Oxygen admitted to Bed.	Carbon Dioxide produced. Per cent. of Air in Bed.
2-11-1899.				
Crude sewage	12·47	...	...	...
Effluent from gravel, 5–7 mm.	6·43	48·5	32·4	2·6
„ „ 5–7 mm. + nails	5·11	59·0	91·8	2·9
Effluent from coke, 5–7 mm. .	5·11	59·0	52·2	1·6
„ gravel, 5–7 mm. + limestone . . .	6·19	50·3	36·7	2·7
9-11-1899.				
Crude sewage	10·94	...	...	...
Effluent from gravel, 5–7 mm.	5·62	48·6	65·2	7·2
„ „ 5–7 mm. + nails	4·71	57·0	100·0	4·7
Effluent from coke, 5–7 mm. .	4·75	56·6	71·0	4·9
„ gravel, 5–7 mm. + limestone . . .	5·41	49·6	70·0	7·3

It will be seen that the gravel containing nails caused a greater reduction in the oxygen absorbed than the gravel to which no nails had been added, 59·0 as against 48·5 per cent. The effluent was equal to that produced by the coke bed. Of the oxygen admitted to the bed containing iron, 91·8 per cent. was used up, as against 32·4 per cent. in the other bed. Seven days later the results were practically the same, because the oxygen which gained access to the beds was limited. With beds freely exposed to the atmosphere, the following results were obtained:—

EFFECT OF IRON ON CONTACT BEDS.

Bed.	Months in Operation.	Oxygen Absorbed (parts per 100,000).		Percentage Reduction in Oxygen Absorbed.
		Crude Sewage.	Effluent.	
Gravel, 5–10 mm.	1	7·55	3·35	55·6
	2	7·95	2·70	66·0
	3	8·40	2·70	67·9
	4	9·00	3·12	65·3
Gravel, 5–10 mm. + 1 per cent. iron	1	7·55	3·17	57·9
	2	7·95	2·35	70·4
	3	8·40	2·17	74·1
	4	9·00	2·42	73·1

From these results it cannot be doubted that a certain quantity of iron in the material of contact beds exerts a favourable influence on the processes of absorption and oxidation.

That the results produced with pumice-stone were not as good as those produced with coke is due to the fact that the pumice-stone was free from iron, whilst the coke contained iron favourably distributed throughout its mass. Even in a perfectly smooth non-porous material, such as river gravel, the absorptive action may be considerably increased by addition of iron. Care must, however, be exercised with such addition, otherwise the bed may easily become clogged.

The opinion has been repeatedly expressed that a certain addition of lime to contact beds increases their action. Attempts have also been made to obtain better results by adding lime to the sewage. The figures in the table on p. 173 show that lime did not exert a beneficial influence on the biological processes. Any better results produced by addition of lime to sewage are most probably due to precipitation of solids preventing them reaching the contact beds, or in rare cases when the sewage is acid, to neutralisation, for absorption is interfered with by acid sewage.

The Maturing of Filters.—It is well known that newly constructed biological filters do not at first yield a non-putrescible effluent. It has been shown, however, that coke is better in this respect than gravel. *Reasons for* this behaviour are furnished by the above experiments.

During the first few weeks of operation the purification effected by biological filters increases from day to day. This is explained as follows: (1) The absorbed substances are deposited on the separate particles of the material composing the filter. This is demonstrated by the above experiment in which the gravel soon became encrusted with iron dissolved from the nails. (2) The suspended matters which gain access to the filter and the matters precipitated on the material by absorption are not completely decomposed, but only deprived of their easily decomposable constituents. A not inconsiderable portion, similar in character to humus, remains on the surface of the gravel or clinker, and this, like the iron, increases the absorptive power of the filter. The gelatinous nature of this coating, to which in the preceding chapter we attributed the character of a surface film, is increased by the micro-organisms and higher forms of life, both animal and vegetable, which soon begin to inhabit the filter. In contact beds the higher forms of life predominate near the surface, where they are able to obtain sufficient oxygen and where they obtain nourishment from the accumulating sludge, which they break up and loosen to a remarkable extent.

The sequence of these processes is so much to the purpose that in studying them one repeatedly forms the impression that they were expressly designed by nature. All the chemical and biological processes described above unite in order to increase the action of the filter in separating dissolved organic solids.

One might almost say that the animal and vegetable forms of life strategically seek out the weakest points, in order to decompose the retained solids. In proportion as these actions increase, more oxygen is necessary, and the maturing process creates conditions by which oxygen is drawn into the filter from the surrounding air with increasing energy. The heat which is developed by the processes of oxidation serves to accelerate the processes of diffusion, and the oxygen which enters the filter is consumed by the surface film with increasing eagerness.

Nature furnishes the means for producing the necessary results. It is only needful for man to perform his part, to understand the reactions which take place, so that he may assist the biological process in a suitable manner and at the proper place, and not retard the process, as is actually done in many instances. The most common error in this direction is to underestimate the importance of periods of rest and to believe that the works are in order so long as they do not yield putrescible effluents. We have seen, however, that a biological filter is to be compared, so to speak, with a noble racehorse, which often attempts more than it is capable of performing. The filter continues to separate organic matters from the sewage even after it ceases to be able to decompose and mineralise them. These undecomposed substances then accumulate in the pores of the filter, which is thus rendered impermeable. Oxygen cannot enter, the higher forms of life die, decomposition ceases, and the filter is "worked to death."

The overworking of biological filters leads, as we have seen from the experiments described above, to an accumulation of carbon dioxide, which considerably aids the weathering of the filtering material. The rapidity with which the consequences of overworking are shown in contact beds may be illustrated by the fact that a contact bed filled six times a day had lost two-thirds of its capacity by the 150th filling; whereas, when filled only once a day, it had only lost six per cent. of its capacity after 300 days. In this respect gravel beds are, when freshly constructed, worse than coke beds, but on reaching maturity they work well. If they are overworked they become mature more quickly in consequence of the accumulation of undecomposed organic matter, but in such cases maturity is soon followed by clogging, and the beds are worked to death. Coke and clinker do not clog so quickly as gravel. We have already seen that the finer the material the greater the purifying action of the filter, but at the same time the filter becomes more easily clogged. Even when carefully managed, fine-grained contact beds will not purify as much sewage as coarse-grained. The following table gives information on this point:—

EFFECT OF SIZE AND NATURE OF MATERIAL UPON CAPACITY OF CONTACT BEDS, AND PURIFICATION PRODUCED.

		Size of Material (in mm.).					
		2–3.	3–5.	5–7.	7–10.	10–20.	10–30.
Gravel	Capacity. Percentage of volume . .	26·5	28·8	32·9	33·5	34·4	...
	Percentage reduction in oxygen absorbed .	61·8	61·8	57·1	56·6	46·5	...
Coke	Capacity. Percentage of volume . .	40·6	44·0	45·5	42·9	43·4	51·8
	Percentage reduction in oxygen absorbed .	...	69·0	64·6	62·5	51·0	44·2

The figures were determined on the tenth day of operation of the beds. During the first few days variations are caused by the irregular wetting of the material. Beds of gravel 2 to 3 mm. in size were able to take 26·5 per cent. of their volume of sewage, 10 to 20 mm. material took 34·4 per cent.; coke beds of material 2 to 3 mm. in size took 40·6 per cent. of their volume of sewage, 10 to 20 mm. material took 43·4, and 10 to 30 mm. material took as much as 51·8 per cent. Coke then is superior to gravel in this respect, as well as with regard to the purification produced, as may be seen from the above table, which also supports the experiments previously described.

The following table further shows the effect of the nature of the material upon the capacity of contact beds, and the purification produced.

The table also contains the figures obtained on first wetting the material, in order to show the different results obtained in comparison with later fillings as well as with the various kinds of material.

EFFECT OF SIZE AND NATURE OF MATERIAL UPON CAPACITY OF CONTACT BEDS, AND PURIFICATION PRODUCED.

	No. of Filling.	Animal Charcoal. 3-7 mm.	Wood Charcoal. 3-7 mm.	Pumice-stone. 3-7 mm.	Clinker. 3-10 mm.	Coke. 3-7 mm.	Gravel. 3-7 mm.	Coke. 10-30 mm.
Capacity. Percentage volume	1*	77·1	69·1	62·4	60·7	42·1	41·2	55·6
	2	55·1	57·3	52·7	50·8	36·5	33·9	53·7
	10	46·1	56·7	44·4	45·9	...	26·7	51·8
	50	43·9	46·7	38·1	35·3	35·1	19·4	48·8
Percentage reduction in oxygen absorbed	1*	45·1	36·7	18·0	14·3	...	...	...
	2	72·1	38·9	22·4	31·0	85·8	51·4	37·6
	10	78·7	62·5	40·5	47·8	87·3	83·4	34·2
	50	77·6	69·6	63·0	77·7	87·0	85·8	26·5

* First wetting of material.

After fifty fillings, pumice-stone, clinker and coke beds have practically the same capacity. Beds of wood charcoal and animal charcoal give higher figures, but they may be excluded as unsuitable on account of their high price. The capacity of gravel beds is considerably lower than that of other material.

Not only does the capacity of the beds vary with the nature of the material, but also with the rate at which sewage will sink into the beds. With beds of coke, clinker, and pumice-stone, 3 to 7 mm. in size, the sewage sinks into the bed immediately, even after the fiftieth filling and when the sewage is supplied at a high rate. With gravel of 3 to 7 mm. size, the sewage soon begins to pond on the surface, chiefly because the air cannot readily escape from the bed after it has become mature and somewhat clogged in the surface layers. If the beds are filled from the bottom, the filling is more easily accomplished.

The above remarks serve to show that the biological method, even in its simplest form, possesses a multifarious character, and also that varied requirements may be met as regards the extent of the purification and the volume of sewage to be treated on a given area. If the degree of purification is to be as high as possible, fine material must be employed. But in this case the action of the filters cannot be forced to the same extent as with coarser material. By a little artifice, such as the addition of metallic iron, the action of a material which is otherwise not very suitable may be considerably increased. But if this addition is not carefully carried out, the clogging of the filter is accelerated. Each of the nails added to our contact bed soon became coated with large quantities of hydroxide of iron, which caused the gravel to form masses the size of hazel nuts and even larger.

Sludging-up.—The second question which we attempted to answer by our experiments was whether the gradual sludging up of the contact beds had to be taken into account, and if the weathering action on the material could be kept within such limits as to increase the life of the contact beds sufficiently for economic requirements. Ten years ago, when our experiments were commenced, they seemed specially necessary. Our results were not in agreement with those of other observers. Even after years of observation, the experts of various English towns stated that only at first was there any appreciable decrease in the capacity of contact beds, and that it soon became practically constant. Our experiments gave a different result, and experience has now shown that we were in the right.

The experts who formerly opposed our views now exhibit with pride the apparatus which they have in the meantime constructed in order to regenerate their sludged-up contact beds. After about five years' operation, the regeneration of the contact beds has proved to be necessary, and is carried out in a manner which, as a result of our experiments, we characterised ten years ago as the only possible one. Periods of rest and the raking over of the beds do not produce the necessary result. The beds must be taken to pieces and the adhering sludge washed from the material. The simple method illustrated in fig. 89 was sufficient for our purpose to restore the original capacity of the bed. Even a few years ago it was everywhere believed in England that contact beds could be fully regenerated by resting; to-day it is well known that such is not the case. If we examine a contact bed which has been operated so long that it must be regenerated, we see exactly the same changes as we described from the results of our experiments. In the deeper portions of the bed the clinker is plastered over with a blackish substance. When exposed to the air this

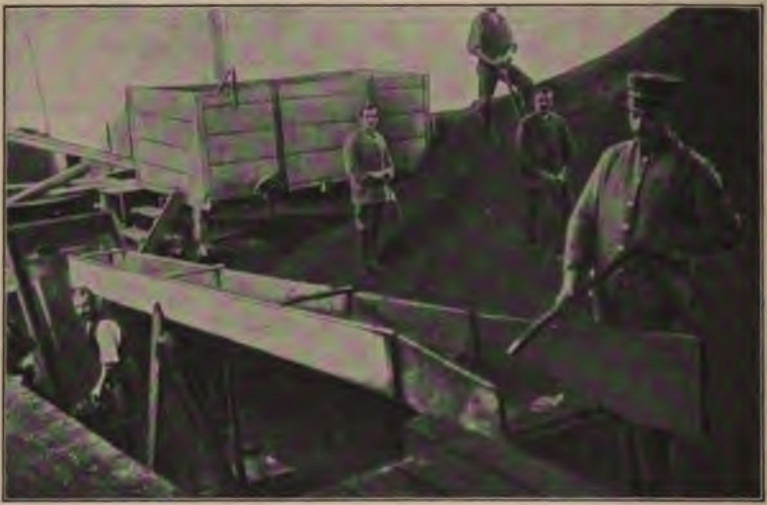


FIG. 89.—Hamburg Method of Washing Contact Beds.

substance rapidly turns brown. The want of sufficient air in the bed had led to the deposition of sulphide of iron, which is oxidised in the air, the sulphur being converted into sulphuric acid. The iron, however, is again deposited in the filter and cannot be removed by simply swilling the material *in situ*. The bed must be taken to pieces and the separate particles of material thoroughly washed.

Although a satisfactory agreement now exists with regard to this important question, I should like to give a few data from our earlier experiments, because exactly the same problem, in a somewhat different form, is arising with regard to percolating filters which have lately come so much to the fore.

The suspended matters which are washed out of percolating filters and appear in the effluent are often termed "colloids." The name is quite inappropriate. Some of the dissolved organic matters in sewage are colloids, but these are absorbed in the biological filter and so far decomposed that only humus bodies remain. These are loosened and washed out of the filter. It would therefore be less likely to lead to misunderstanding, and get more at the root of the matter, if one referred to these bodies as "humus flakes," or, as has been done at Accrington from the beginning, "peaty matter." The washing out of this matter from suitably constructed percolating filters may be imagined as taking place in the manner described by Lübbert in connection with tannery refuse. The tannic acid and the tannates from tannery refuse are absorbed in the biological filter and there precipitated. They may then be regarded as a thin membrane surrounding the slag. Beneath this membrane hydroxide of iron is formed until it splits the membrane, which can then be washed out in the form of small flakes. If the filter is constructed with fine material below coarse, as is often the case, these substances cannot be washed through, with the result that a percolating filter becomes clogged up, just like a contact bed. If it is intended to prevent such clogging, and this will always doubtless be the case, such a grading of the material must be regarded as an error.

From the results of our observations upon the sludging up of biological filters, I will here select a few typical examples. A contact bed constructed of clinker 3 to 7 mm. in size was filled once a day for twenty-six months with sewage. The bed remained full for four hours and aerating for nineteen, filling and emptying together occupying one hour. The average reduction in the oxygen absorbed was 70 per cent. The effluents were always non-putrescible, and had an earthy or musty odour. The capacity of the bed, after being previously thoroughly wetted, was 31·9 per cent. during the first 50 fillings, after 200 fillings it had sunk to 30·3, after 500 to 26·0, and after 700 to 19·9 per cent. During a little over two years' working the bed had lost over 40 per cent. of its original capacity.

Another similarly constructed contact bed was filled twice a day. The first filling was allowed to remain in the filter for four hours and the second for two hours; the aeration lasted for four and twelve hours respectively, the two fillings and two emptyings occupying the remaining two hours. The bed was in operation for fourteen months, and produced a reduction in the oxygen absorbed of between 70 and 80 per cent., usually rather higher than with the daily filling. The effluents were non-putrescible, and had an odour of humus, like natural water derived from peaty gathering grounds. The capacity at the first filling every day was larger than at the second, because during the twelve hour period of aeration the bed had a better opportunity of draining. After previous wetting, the capacity of the bed during the first 50 fillings was 38·9 per cent., rather higher than in the first experiment After 200 fillings the capacity had decreased by 25 per cent. of its original value, after 400 fillings by rather over 40, and after 700 by about 64 per cent. The capacity sank from about 40 per cent. of the total volume of the bed to about 15 per cent. The clogging of the bed took place, therefore, more quickly than when the bed was filled once a day.

In a further experiment the contact bed of 3 to 7 mm. sized material received the effluent from a contact bed constructed of coarse clinker. After 700 fillings, at the rate of two daily, the capacity of the contact bed had fallen from 36·0 to 21·9 per cent. of the volume of the bed. This reduction amounts to about 39 per cent. of the original capacity.

From the above it is evident that the clogging of the beds may be retarded in two ways, either by feeding with small quantities of sewage, or by submitting the sewage to a preliminary treatment. In both cases the cost of the works would be increased. It becomes a purely financial question, dependent upon local conditions, whether smaller works shall be constructed at a small original cost with a large outlay for cleaning, owing to clogging of the beds, or whether works shall be constructed larger in the first instance at a larger original cost in order to put off the expenditure on regeneration of the beds.

The sewage which was used in the above experiments had passed through a detritus tank, and was therefore free from the coarser suspended solids. Since then it has been shown that a more thorough removal of the suspended matters is always advisable before adopting contact beds. Even if the sewage is first treated in coarse primary beds, *i.e.* submitted to a treatment more thorough than can be attained by settlement, septic action, or chemical precipitation, a gradual clogging of the beds takes place. In an experiment with a bed constructed of gravel 3 to 7 mm. in size, charged twice a day with the effluent from a primary bed constructed of coke 10 to 30 mm. in size, the capacity of the gravel bed sank from 25·8 to 13·9 per cent. after 500 fillings. The capacity of a secondary coke bed constructed of material of the same size, and receiving the effluent from a primary coke bed constructed of 10 to 30 mm. material, sank from 35·1 to 25·0 per cent. after 550 fillings. If we compare these results with those obtained with clinker beds, the comparison is in favour of clinker; for, without any preliminary treatment of the sewage, the capacity of a clinker bed constructed of 3 to 7 mm. material, when charged twice a day, sank from 38·9 to 18·4 per cent. after 550 fillings.

In another experiment sewage was treated in a primary clinker bed of 10 to 30 mm. material and in a secondary clinker bed of 5 to 10 mm. material. After 500 fillings the capacity of the secondary bed had sunk from 38·4 to 26·2 per cent., and after 800 fillings to 23·1 per cent.

The clogging of the bed also varies with the character of the liquid which has to be purified. The following table gives information on this point:—

EFFECT OF CHARACTER OF SEWAGE ON CAPACITY OF CONTACT BEDS.

Date, 1900.	No. of Filling.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
		Drinking Water.	Dilute Urine.	Sewage.		Drinking Water with Fæcal Matter.	Sewage precipitated with		
				Filtered.	Unfiltered.		Lime.	Lime and Iron Salt.	Chloride of Iron.
		Capacity (Percentage Volume of Bed).							
Apr. 9	1	47·9	47·0	48·4	48·2	47·7	...	...	...
,, 10	2	40·0	39·2	43·9	41·8	43·2	44·4	47·5	48·0
,, 17	8	40·3	38·4	43·7	40·9	40·2	42·0	41·6	47·8
,, 23	14	40·3	38·0	42·1	40·3	41·0	39·8	43·1	44·0
,, 30	21	40·0	39·0	42·6	39·2	40·7	38·6	43·5	43·3
May 7	28	40·1	37·9	41·3	38·1	40·4	39·1	43·4	42·9
,, 14	35	40·2	37·9	40·2	37·8	38·8	38·4	41·6	42·9
,, 21	42	40·1	37·4	39·4	37·3	38·1	37·5	41·1	41·3
,, 30	51	40·2	37·9	39·4	37·3	38·1	37·5	42·5	41·1
June 11	63	42·1	38·6	38·3	39·8	39·3	42·4	42·8	41·1
,, 18	69	40·2	39·2	41·3	39·2	39·0	37·7	43·4	40·5
,, 26	75	41·5	38·3	40·6	41·5	39·0	37·6	40·0	39·1
July 16	92	41·6	39·6	43·3	38·0	39·0	38·7	40·1	37·5
,, 23	98	40·7	39·3	43·3	38·0	38·5	38·7	40·1	37·5
Aug. 7	113	40·7	39·8	40·1	37·8	37·4	37·2	40·1	37·5
,, 15	121	40·7	39·0	40·0	37·8	36·1	37·3	40·0	37·5
,, 23	134	40·2	37·1	39·6	37·4	35·7	36·5	39·9	36·5
Percentage reduction in capacity .		16·1	21·1	18·2	22·4	26·6	17·8	16·0	23·9

Even when charged only once a day and allowed to stand full for four hours, the capacity of coke contact beds was reduced by 16·1 per cent. during four months, when drinking water was used, *i.e.* when no biological action took place. The same bed, when charged with dilute urine, *i.e.* with a liquid free from suspended solids, had its capacity reduced in this short period by 21·1 per cent.; when charged with filtered sewage by over 18 per cent.; and when charged with chemically precipitated sewage by 16 to 24 per cent. It should be noted that the chemically precipitated sewage was also filtered in order to free it as far as possible from suspended matter. It could not be more clearly demonstrated that under all circumstances contact beds do gradually become clogged. If, however, the suspended solids are of an organic decomposable nature, the process of clogging is not greatly accelerated thereby.

In a comparison made with four contact beds constructed of various material of 3 to 7 mm. size, and receiving sewage in exactly the same manner, a clinker bed contained 8·22 per cent. of its volume of sludge, a bed constructed of pumice-stone 5·67 per cent., a bed of wood charcoal 5·00 per cent., and a bed of animal charcoal 5·44 per cent. In another comparative experiment, after 80 fillings, a coke bed constructed of 2 to 3 mm. material contained 4·55 per cent. of its volume of sludge; whereas a 10 to 20 mm. bed contained only 2·60 per cent.; a gravel bed of 2 to 3 mm. sized material contained 3·13 per cent.; one of 10 to 20 mm. sized material, 2·25 per cent.; and a gravel bed of 5 to 7 mm. sized material, mixed with nails, contained 4·67 per cent. of sludge.

Calculated on the volume of sewage which the beds had treated, the amount of sludge remaining in a clinker bed of 3 to 7 mm. material, after 725 fillings, was 0·133 per cent. when the bed was charged once a day, and 0·168 per cent. when charged twice a day. Coke, clinker, gravel, and broken bricks gave much lower figures when the material was coarser (10 to 30 mm.). Coke, *e.g.* after 1600 fillings, yielded sludge to the extent of 0·034 per cent. of the volume of sewage treated; clinker, after over 1000 fillings, 0·017 per cent.; gravel, after about 950 fillings, 0·028 per cent.; and broken bricks, after 900 fillings, 0·044 per cent. The following table shows that the sludge deposit is greater in the upper than in the lower layers of the filter:—

Amount of Sludge at various Depths in Contact Beds.

Size of Material (mm.).	Depth in the Bed (cm.).	Drained Sludge, expressed as per cent. of Volume of Bed.	
		One Filling per Day.	Two Fillings per Day.
3-7	10-20	27·8	25·8
	20-30	25·7	23·8
	30-50	19·4	18·2
	50-70	16·4	18·0
	70-90	17·2	19·0
10-30	90-100	7·6	9·9

All possible variations of the above experiment were carried out, using different material, such as broken bricks, stones, etc., but the results all pointed in the same direction.

The most important result is undoubtedly the fact that contact beds clog up, even when constructed of material which is very resistant to weathering action; and that such material is inferior, as regards the amount of sewage treated and the purification effected, to material which is porous and less resistant to weathering action.

Loss of Material.—The results obtained after five years' working in *English towns* show that the loss of material on washing contact beds varies, with the nature of the material, from 20 to 25 per cent. In our experiments we only lost 9·4 per cent. It should be noted, however, that our experiments were of shorter duration, and that the clinker had in the first place been very carefully sieved, which had not always been the case at the larger works in England, and hence the loss was not entirely due to weathering action, but partly to a washing away of the finer material.

The data from the separate experiments are contained in the following table:—

LOSS OF MATERIAL ON WASHING CONTACT BEDS.

Size of Material (mm.).	Coal.		Coke.		Gravel.	
	Before Washing (per cent.).	After Washing (per cent.).	Before Washing (per cent.).	After Washing (per cent.).	Before Washing (per cent.).	After Washing (per cent.).
Experiment a.						
under 2	4·0	0	7·8	5·5	2·5	0
2-4	13·1	9·9	14·4	11·9	15·5	20·2
4-5	30·3	10·4 } 22·8	23·5	12·7 } 26·6	42·7	19·6 } 39·8
5-6		12·4		13·9		20·2
6-8	48·2	36·2 } 58·8	40·6	30·2 } 45·0	34·8	27·2 } 35·0
8-10		22·6		14·8		7·8
over 10	4·2	8·5	13·7	11·0	4·5	5·0
Experiment b.						
under 4	15·0	53·3	...	...	...	..
4-5	21·0	12·5	...	...	...	...
5-6	46·0	15·5 } 25·0	...	...	...	...
6-8		9·5				
8-10	18·0	4·1 } 9·4	...	...	...	...
over 10		5·3				

The alteration in the size of the material is the same as that observed in sand-washing in connection with waterworks undertakings. After washing, the size is somewhat larger than that of the original material. It was also shown (Experiment *b*) that coke and clinker which had once been washed was more resistant to weathering action than before being sludged up. During the first period of working, therefore, those portions of the material are lost which are most easily weathered.

The sludge washed out of the beds was of the nature of humus. According to the kind of material used in the construction of the beds and the method of working, the sludge contained 60 to 75 per cent. of moisture, and the loss on ignition amounted to 4 to 6 per cent. The total nitrogen varied from about 0·5 to 1·0 per cent. The sludge is easily drained, and may be used for raising the level of the land or for improving the surface soil.

In order to diminish the clogging of the beds, to enable the washing to be carried out as simply as possible, and thus to reduce the cost, W. J.

Dibdin has constructed primary beds of broken slate, a waste product of the slate industry, instead of using slag and similar porous material. The layers of slate are separated by means of small slate blocks. Dibdin asserts that by far the larger portion of the suspended solids, and of the solids which can be separated from the sewage, are robbed of their putrescibility by the biological processes taking place on the slates, and can then be washed out by means of a hose-pipe. His reports upon the slate beds at Devizes, where experiments were commenced in September 1905, and upon others at Trowbridge, are very favourable, but the process does not appear to me to be rational.

Emptying and Filling the Beds.—The construction of contact beds is so simple that any further description appears unnecessary. With regard to the method of working, little need be said, since it has already been pointed out that long periods of aeration are important, and that therefore the sewage should not be allowed to remain too long in the bed. If the sewage is allowed to remain too long in the beds it begins to smell of sulphuretted hydrogen, due to the reduction processes which take place as soon as all the oxygen in the beds is used up. It is, therefore, very important that great care should be bestowed on the working of the beds. They should not be filled gradually at the same rate as the sewage is produced, but as quickly as possible; and they should never be allowed to remain full for more than four hours. Practical men are fully aware of the difficulty of carrying out all these operations by hand, especially in the case of small works, where it is not always possible to appoint responsible persons for this purpose. Hence, numerous forms of apparatus have been devised for automatically filling and emptying the beds. They are generally expensive, as well as complicated, and their regular working is often disturbed by small unforeseen causes. In this direction many unfavourable reports are available. At Manchester, after testing various automatic devices, it has been decided to operate the contact beds by hand.

A comparatively simple apparatus for automatically filling and emptying contact beds, devised by S. H. Adams of York, may serve as an illustration. From the sewer (A, fig. 90), the sewage enters the syphon (B), which is connected by means of the pipe (C) with the air-vessel (D). Through the syphon the sewage enters the contact bed (G). The perforated wall (F) serves to prevent the material of the bed from falling into the regulating chamber (E). In fig. 90 the apparatus is shown at a stage before the bed is completely full. As the filling proceeds, a stage is reached, which is depicted in fig. 91. The sewage reaches the air-vessel (D), and compresses the air which it contains, until this air is pressed into the syphon (B), which is thus put out of action, and the entrance of sewage to the bed is stopped. The bed remains full until the air is driven from the syphon of a similar apparatus at the outlet end of the bed. As soon as one bed is filled, the sewage flows into another in which the air-vessel has been emptied of sewage; and if there are several beds, the various air-vessels can be connected in such a manner that the sewage enters the beds automatically at definite times. The action is due to the injection or ejection of air from a syphon similar to the one shown in figs. 90 and 91.

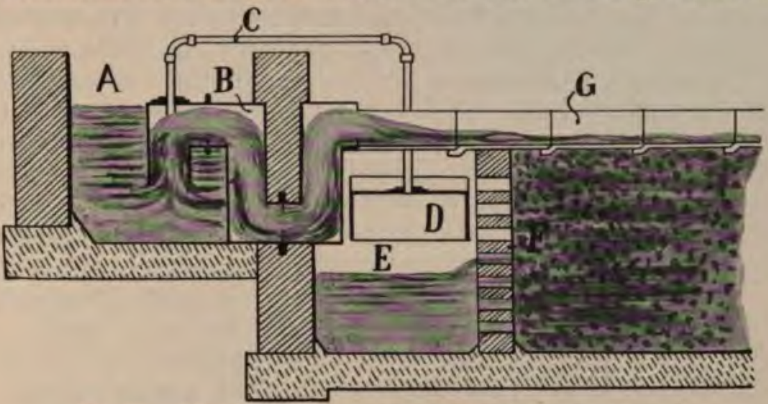


FIG. 90.—Adams' Automatic Feed for Contact Beds. Bed Filling.

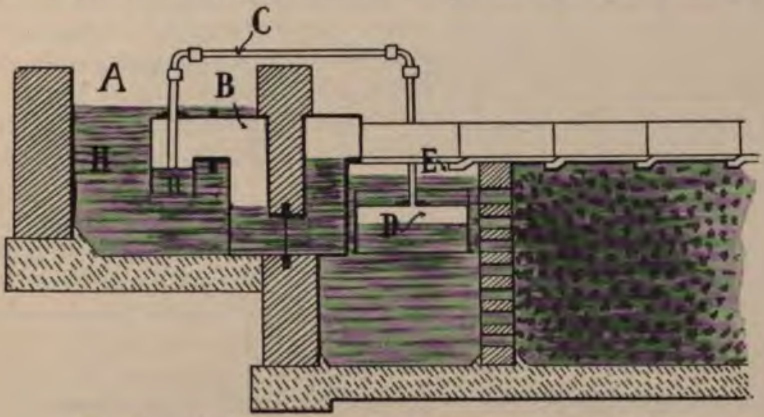


FIG. 91.—Adams' Automatic Feed for Contact Beds. Bed Full.

In fig. 92 a system of double contact beds is shown, fitted with an Adams' apparatus. The sewage first enters the detritus tank (S), from which the deposit is removed by means of a dredger; it next flows over the submerged wall (T) into the septic tank (U), from which the sediment can

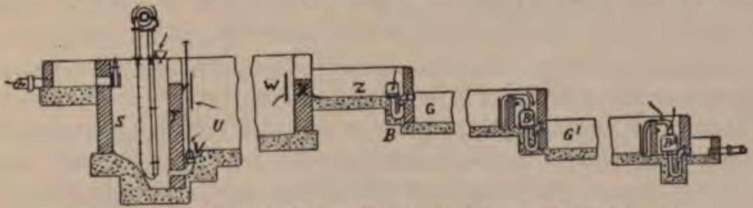


FIG. 92.—Double Contact Beds fitted with Adams' Automatic Feed. Longitudinal Section.

be discharged through the well (V) into the detritus tank. Passing beneath the scum board (W), and over the submerged wall (X), the sewage enters the distributing tank (Z). From here the sewage enters the bed (G) through Adams' automatic distributing apparatus (B). As soon as the bed (G) is full, the syphon (B) fills with air and the sewage flow is stopped. After a certain time the air is expelled from the syphon of an apparatus (B¹) at the outlet end of the bed. The primary bed (G) then empties through the apparatus (B¹) into the secondary bed (G¹), where the operation is repeated. The same system is shown in plan in fig. 93.

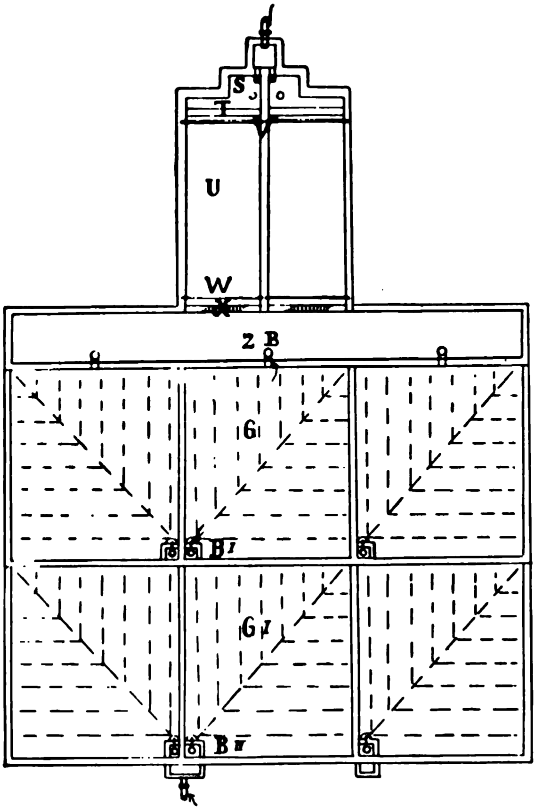


Fig. 93.- Double Contact Beds, fitted with Adams' Automatic Feed. Plan.

Results Obtained.—As regards the amount of sewage which can be dealt with, it was shown above that the contact process is superior to either land filtration or irrigation. It is, however, inferior to the percolating process about to be described. In this latter process the volume of sewage which can be treated does not diminish, because of the gradual clogging of the beds, to the same extent as in the contact process. Clogging may be considerably lessened by a preliminary removal of the suspended solids from the sewage, either by settling tanks, septic tanks, chemical precipitation, or even by means of primary beds constructed of coarser material.

Special importance should also be attached to a thorough drainage of contact beds. In the earliest beds constructed, many errors were made in this direction. The sewage was intended to flow away through channels covered with perforated plates; the holes in these plates soon became stopped up, and the beds could not run dry: weathering and sludging up were accelerated, and the qualitative and quantitative results produced by the beds were considerably interfered with.

Generally speaking, the effluents from single contact beds are not so good as those from either land filtration or irrigation. It is, however, easy to obtain non-putrescible effluents from contact beds, and thus to fulfil the usual requirements, but the effluents are rarely perfectly clear, especially after single contact. The effluents from carefully constructed contact beds do not contain any suspended matter derived from the crude sewage. They are, however, opalescent; but on standing exposed to the air they become clear, and deposit small quantities of a brown substance, which is found to contain iron as well as numerous bacteria and other forms of life. The effluents are rarely free from odour; they usually have a slight earthy or musty smell.

The amount of nitric acid in the effluents from contact beds is usually less than in those from land filtration and irrigation, as well as from percolating filters. This is due to the fact that in contact beds the nitric acid formed is exposed to reducing actions which may cause it to almost entirely disappear. At the present day, however, it is generally recognised that too much importance was formerly attached to the presence of nitric acid in the effluents; in other words, the biological purification of sewage does not aim at the production of nitric acid, and the amount present in an effluent is not an infallible index of the degree of purification attained, but only in some measure a safety co-efficient. The more nitric acid is present in an effluent the greater is the guarantee that not only has the necessary purification been effected, but that it has certainly been exceeded

Bacteriologically considered, the effluents from contact beds are inferior to those of the other biological processes. The number of bacteria in the effluent is generally less than in the crude sewage, but always high.

Percolating Filters.

Advantages and Disadvantages.—The contact method described above differs from all other methods of biological purification in that all the pores of the bed are filled with sewage and allowed to remain full for some time. The opinion prevailing at the present time with regard to irrigation and land filtration is also to the effect that each dose of sewage remains in the pores of the soil until it is expelled and replaced by a fresh dose. In the chapter dealing with land filtration this view was shown to be erroneous, for the sewage passes through the soil in a few minutes, and there is only a limited exchange with the liquid previously adhering to the soil. The soil only contains a quantity of liquid equal to its water-retaining capacity, *i.e.* 16 to 18, or at most 20 per cent.; the volume of the pores is considerably more than this. During the whole period of operation an exchange of gases can take place between the soil and the surrounding atmosphere. It is otherwise in the contact process; for one or several hours the biological processes and the exchange of gases with the surrounding atmosphere are stopped, and this must be regarded as a disadvantage inseparably connected with this method of treatment. In each individual case this disadvantage must be weighed against the advantages described in the previous section.

In 1893, Corbett of Salford developed the artificial biological method in an entirely new direction. This he did independent of the London experiments, basing his experiments on the results obtained in Massachusetts. Corbett attempted to apply the principle laid down by Sir E. Frankland, and recognised to be correct by the Massachusetts authorities, viz., that in intermittent filtration the liquid should always be allowed to flow freely away. In adopting coarse material in order to purify larger volumes of sewage, it had been found difficult to bring the sewage into sufficient contact with the filtering material. It simply passed through the large pores of the filter unpurified. We have already seen how attempts were made to overcome this difficulty in Massachusetts by means of an automatic syphon arrangement, which discharged sewage on to the filter every twenty or thirty minutes. This method was not directly applicable on a large scale. The chief difficulty to be overcome was to obtain a uniform distribution of the sewage over the entire surface of the filter. After many experiments in various directions, Corbett adopted for this purpose fixed spray jets from which the sewage was distributed under pressure in the form of a fountain. At this point it should be mentioned that, in Corbett's opinion, he was the first to place a layer of half pipes underneath the filters, in order to increase aeration and facilitate drainage.

In the biological method the dissolved organic matters, as we have seen, are separated from the sewage by surface attraction, and absorbed by the gelatinous film containing vegetable and animal forms of life. The more thorough, then, the contact between the sewage and the filtering material, the better and more easily will the purification be effected. Such conditions are best fulfilled by the adoption of such a method as the one selected by Corbett, in which the sewage falls on the surface of the filter as single drops; each drop spreads over the surface of the piece of clinker on which it has fallen, gradually collects on the lower surface of the material, or on some projection, in the form of a drop, which then falls on to the next lower piece, and so on until the bottom of the filter is reached. Under such conditions absorption processes are much more favoured than in contact beds, into which the sewage is charged in a comparatively strong current, which washes off part of the growths and humus deposit, quickly reaches the bottom of the bed, and as its level gradually rises, fills the pores without each particle of liquid coming in contact with the surface of the material. Moreover, in Corbett's method of operation the air can continually circulate through the filter, make up any deficit of oxygen, and carry away the carbon dioxide which has been formed. The danger of intense weathering action is thus diminished. Vital activity too, not only of the micro-organisms, but also of the higher forms of life, is encouraged by the better aeration which takes place in percolating filters.

The conditions in a percolating filter are far more favourable for the processes of absorption, decomposition, and oxidation than in a contact bed, and hence it becomes a question merely as to whether the even distribution necessary for percolating filters does not present greater technical difficulties and cost more than carrying out the contact process.

In the contact process one great disadvantage is that the filling and emptying of the beds must be carried out regularly, or bad results ensue. We have seen how this regularity has been sought to be attained by means of automatic apparatus; but such apparatus is generally either expensive or unreliable, and has failed to give satisfaction. With percolating filters many of the forms of distributing apparatus at first devised were also unreliable. The conviction soon gained ground that percolating filters were capable of treating much larger volumes of sewage than contact beds. At present, contact beds are constructed of such a size that they have not to deal with more than half a cubic yard of sewage per twenty-four hours on each cubic yard of bed. When percolating filters were first introduced they were credited with extraordinary capabilities. Just as with contact beds their capabilities were originally very much overestimated.

It must be regarded as a great advantage of percolating filters that they need not necessarily be constructed of fine material in order to effect a high degree of purification. There is, therefore, less danger of clogging than with contact beds. The cost of breaking and sieving the material need not be incurred with percolating filters. Contact beds clog throughout the bed, which necessitates the removal of the material for washing. There is this danger also with percolating filters, if the lower layers are constructed of finer material than the upper. If, however, in the construction of the filters, care is taken to have material of gradually increasing size towards the bottom, the solids can be easily washed through with the effluent. At Leeds it has been shown that sewage which had only passed through a detritus tank, and therefore contained large amounts of solids, could be treated on a suitably constructed percolating filter without any danger of sludging up. The previously mentioned flocculent humus particles are washed out with the effluent, and, since they settle rapidly, a comparatively small settling tank placed after the filters suffices to keep them from the stream. The working of this process is also less of a nuisance than the sedimentation of crude sewage, because the sludge thus obtained is non-putrescible, easily drained, and may be employed for filling-in waste land.

Contact beds must be constructed in water-tight tanks of suitable strength, and this often means considerable expenditure on the construction of walls. Percolating filters, on the other hand, do not require water-tight side walls, since they are never filled with sewage. A water-tight base, or, since the sewage is generally sufficiently purified when it reaches the base, efficient drainage is all that is necessary. The effluent from percolating filters is not discharged suddenly, as from contact beds, but evenly throughout the day, except for the variations in the flow of the incoming sewage. This may be regarded as a considerable advantage, especially for very small streams, on account of the even mixing which takes place in the stream.

Against the above advantages there are only to be placed the following disadvantages: The sewage is cooled more in percolating filters than in contact beds. But even in the cold climate of North America, percolating filters work satisfactorily when the climate is taken into account in choosing the distributing apparatus. Another disadvantage is that the fine distribution of the sewage gives rise to objectionable odours, especially if the sewage has become strongly septic. Finally, it is an undoubted fact that many of the forms of distributing apparatus which have been devised for percolating filters cause a much larger expenditure than can be justified by the increased volume of sewage which can be dealt with.

In 1890 it was shown at the Lawrence Experiment Station in Massachusetts that filters constructed of coarse gravel could be charged with sewage no less than seventy times daily, and yet produce an excellent degree of purification, so long as each charge was only large enough to trickle over the surface of the material and not so large as to fall through the pores.

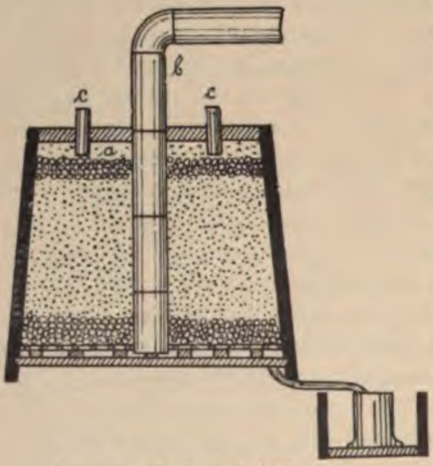


Fig. 94.—Waring's Trickling Filter.

Waring's Filter.—In 1891, Waring patented a filter, and in 1894 constructed one at Newport, Rhode Island. The even distribution of the sewage was effected by a layer of fine gravel (*a*, fig. 94), which was placed over coarser material. This arrangement interfered with the natural aeration of the filter, and Waring considered it necessary to blow the air requisite for the biological processes into the filter through the pipe (*b*). The sewage trickled downwards through the filter, whilst the air rose through the false bottom and upwards through the filter, escaping through the ventilation pipes (*c*). A "strainer" preceded these biological filters. The strainer received sewage at the rate of about $6\frac{1}{4}$ million gallons per acre per day, whilst the filter received the effluent from the strainer at a rate of rather under a million gallons per acre per day. The oxygen absorbed was reduced by the strainer by 51·2 per cent., and after filtration the reduction was 92·5 per cent. on the average, the maximum reduction being 99·08 per cent.

Lowcock's Filter.—In 1892, Lowcock constructed filters at Malvern, and later at Wolverhampton, England, to treat sewage which had previously undergone chemical precipitation. In this case also the distribution was effected by means of a fine top layer of gravel, and, in the lower layers of coarser material, pipes (R, fig. 95) were laid for artificial aeration. The artificial aeration, however, proved to be expensive, and it was very difficult to distribute the compressed air evenly throughout the filter. The purification obtained was very satisfactory. The best results were obtained at a rate of a quarter of a million gallons per acre per day. The oxygen absorbed was reduced by 77 per cent., the albuminoid ammonia by 80 per cent., and the free ammonia by 70 per cent.

Corbett's Filter.—In February 1893, Corbett constructed experimental filters at Salford of sand, gravel, coke, and cinders. He appears to have been the first to use cinders, and he states that at first he had no great hopes of their proving successful. Corbett's filters were not only constructed of evenly graded material, but also in three or four layers of variously sized material, placed one above another. He also tried the effect of leaving an air compartment between the separate layers, so that the sewage might drop from one layer to the other in the form of rain, but the results were in favour of compact filters. The sewage was first led on to the filters by means of wooden troughs laid on the surface of the material; these were next placed several feet above the filters, so that the sewage might fall on to the filters in the form of a shower. Later, experiments were carried out with rotating sprinklers, and finally the spray jets, which have already been mentioned and which will be further described later, were adopted.

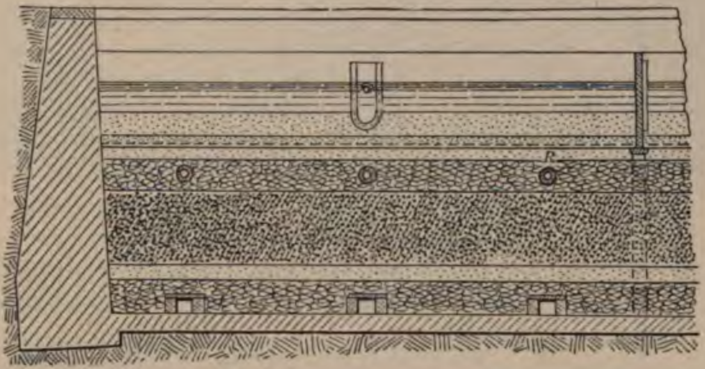


FIG. 95.—Lowcock's Trickling Filter.

Corbett used chemically precipitated sewage in his experiments, and succeeded in thoroughly purifying daily from 500 to 1000 gallons per square yard of filter four feet deep.

Stoddart's Filter.—In 1898, F. Wallis Stoddart of Bristol published a method of distribution for percolating filters, which differs from all other known methods to such an extent that I inquired of him as to what had formed the basis of his apparatus. His reply conveys the idea that in his opinion he was the first to develop an artificial biological process on the percolating system. Frankland's experiments of 1870 (pp. 119, 145), he says, and the work of Schloesing and Müntz and Winogradsky on the biological nature of nitrification (p. 140), had alone formed the basis of his method. His object was to devise a method in which the oxidising micro-organisms could remain continuously at work, without being subjected to the interruptions which occur in land filtration. It should be noted that Stoddart shared the generally prevalent erroneous view of land filtration which was given on p. 139. Stoddart writes that, as early as 1883, he made use of the apparatus depicted in fig. 96 for lecture purposes. The apparatus was exhibited before the British Medical Association in 1894, after the publication in 1893 of a descriptive article. A solution of ammonium sulphate was dropped on to pieces of coarse chalk contained in burettes, and complete nitrification was obtained. The experiment was so devised that air could continuously pass through the chalk along with the liquid. Stoddart perfected his system in the following years, and constructed an installation (figs. 97 and 98) on a practical scale in 1898.

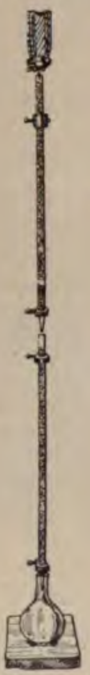


FIG. 96.—Stoddart's Experiments.

When Stoddart states that the Massachusetts experiments have not influenced him in any way in his experiments I have no reason for doubt; but when he goes further, and maintains that the Massachusetts experiments have not contributed in any way to the development of the percolating system, I must differ from him, and uphold the views expressed at the beginning of this chapter. By his publication of 1893, Stoddart, so far as I am informed, did not establish his priority in percolating methods, for at that date Corbett's experiments had already been commenced. With regard to his experiments of earlier date I am not in a position to express an opinion. It is well known that in questions of priority a correct judgment is usually only gradually attained, and the processes here involved are undergoing such rapid development at the present time that definite conclusions upon the historical aspect of the question can scarcely be expected. In view of the fact that Stoddart feels that his contributions have received too little consideration, I have expressed his opinions here at some length.

The construction adopted by Stoddart in 1898 was one in which the sewage was distributed in the form of rain by means of corrugated perforated plates. From the inlet channel (*a*, fig. 97) the sewage overflows into the channels of the corrugated plates (fig. 98). The plates are perforated on the top of the ridges, and the sewage flows through these holes, down the under surface of the plate, until it reaches the small projections at the lowest point, from which it drops on to the filter. The filters themselves are constructed of uniform sized material, cinders or coke, 2 inches to 3 inches in size, and a yard or two in depth, usually 2 yards (fig. 99). The number of distributing projections per square yard is 350 to 400. Stoddart's distributor has been adopted at Horfield and Knowle near Bristol, and has been used for experiments at various places, such as Manchester, Leeds, and Salisbury. The purification produced is satisfactory. The necessary even distribution is only obtained when the distributors are perfectly level, and any deviation causes bad results. Even distribution is also said to be endangered by the growth of fungus in the distributing channels, and hence these have to be periodically cleaned out. The filters deal with five and a half cubic yards of sewage per square yard of filter, or, since the filters are two yards deep, with nearly three cubic yards per cubic yard of filtering material per day. In filters which had no side protection, satisfactory purification was obtained at a temperature of

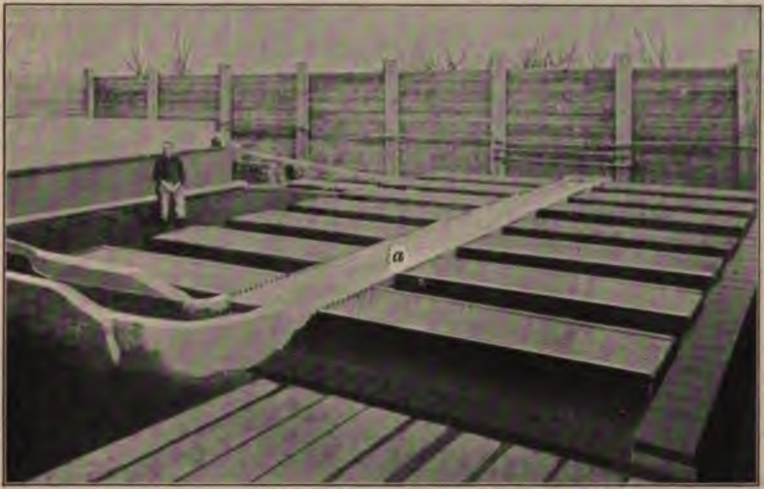


FIG. 97.—Biological Filters on Stoddart's System.

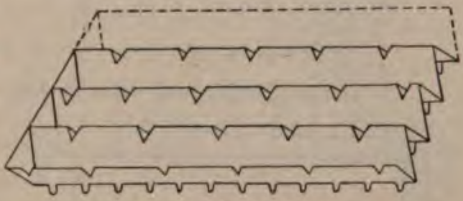


FIG. 98.—Stoddart's Distributor.

$-9{\cdot}5°$ C., although a thick covering of ice was formed in the distributing channels. When treating septic tank effluent at the rate of 1·5 cubic yards per square yard per day, the effluent from the filter contained 1·0 part of free ammonia, 0·28 part of albuminoid ammonia, 7·92 parts of nitric acid, and had an oxygen absorbed of 1·87 parts per 100,000. Calculated on the septic tank effluent, the reduction in the albuminoid ammonia was 84 per cent. and in the oxygen absorbed 73 per cent.

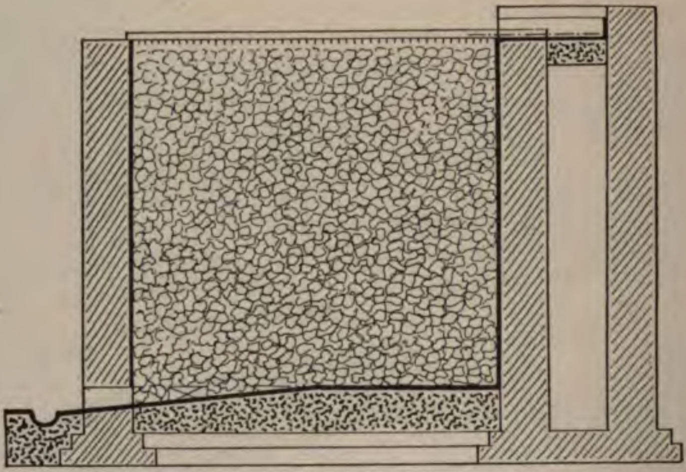


FIG. 99.—Stoddart's Biological Filter. Cross Section.

In the meantime, Corbett had replaced his distributing troughs by fixed pipes, through which the sewage was discharged periodically by means of a syphon (fig. 100).

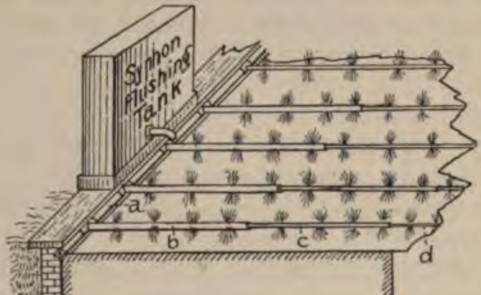


FIG. 100.—Corbett's Sewage Distributor for Intermittent Action.

Garfield's Filter.—In 1896, Garfield used fixed pipes for the distribution of sewage. Garfield's filters were constructed of coal, and the pipes were laid on the surface about 3 feet apart and perforated at points every 3 feet. Coal filters which he constructed at Wolverhampton at that date have given satisfactory results; they were constructed of a total depth of 5 feet, made up as follows: On the bed of the filter a 3-inch layer of ½-inch material was placed, and over this a 25-inch layer of ¼-inch material, followed by a 25-inch layer of material ⅛-inch to ⅕-inch in size. *The top* layer of 7 inches consisted of coal dust, which passed through a

$\frac{1}{8}$-inch mesh. The sewage leaving the perforated pipes under pressure was distributed in the form of a fan by means of metal plates laid over the perforations. The filters were fed continuously for twelve hours and then allowed to rest for twelve hours. At other places the filters were operated in four-hour periods. Chemically precipitated sewage was treated at the rate of 250 gallons per square yard daily. Garfield's process, with certain modifications in the arrangement of the layers of coal, was adopted later at Tipton, Lichfield, Chesterfield, Kimberley, and other places. At Lichfield I have seen the effluent discharged from the filters, and it was perfectly clear, colourless, and without smell. Published analyses show that the oxygen absorbed of the chemically treated sewages was reduced by 70 per cent. on an average. Some experts maintain that coal is especially liable to weathering action; this very probably depends upon the kind of coal. The satisfactory results produced by Garfield's works are to be attributed in the first place to the rational manner in which they have been worked. I have not been able to convince myself that coal possesses any special purifying action greater than that possessed by other materials.

The distribution of sewage over the surface of filters by means of fixed perforated pipes will never be very even. By feeding the pipes from a tank in which the sewage collects and from which it is emptied by syphonic action (fig. 100), the sewage is first sprayed to the further portions of the filter, and, as the water level in the tank sinks, the nearer portions receive their dose. Such primitive arrangements, however, are not as satisfactory as spray jets, to be described later.

A more efficient distribution was attempted by making the perforated pipes movable. They were first mounted at the centre and revolved about this point (rotating sprinklers). Later they were constructed so as to move over rectangular biological filters. Rotating sprinklers only serve circular areas, and the area between the separate circles is not utilised.

Whittaker-Bryant Filter.—After Corbett had experimented, in 1894, with rotating sprinklers, Whittaker and Bryant constructed filters fitted with these at Accrington in 1898, and Candy constructed experimental works at Reigate in the same year.

At Accrington the sprinklers had four arms, each 50 feet long (fig. 101), and were arranged in a group of four, over octagonal shaped filters surrounded by loose walls (fig. 102). The filters were constructed of 2-inch to 3-inch material 8 to 9 feet deep. The sewage was fed to the sprinklers by means of a pulsometer pump, which warmed the sewage at the same time. At that date they, like Ducat, attached much importance to the heating of the sewage, but later experiments at Leeds have shown that no advantage is to be gained by such procedure. Feeding by means of pulsometer pumps proved to be very expensive and was given up. Intermittent feeding is obtained by the arms of the sprinklers passing over the surface of the filters one after the other. The sewage is spread over the surface of the upper layers of material, falls to the lowest point of each piece of material, and then drops to the next lower layer, and so on, until in about ten minutes the bottom of the filter is reached, which is underlaid with half-round perforated pipes (fig. 103). The effluent is clear and non-putrescible, although over 400 gallons of septicised sewage are treated daily per square yard of filter, or rather less than 100 gallons per cubic yard. The reduction effected in the oxygen absorbed amounts to 90 per cent. Flocculent peaty matter gradually began to separate out from the *effluent*; this was at first easily settled out by the introduction of a weir,

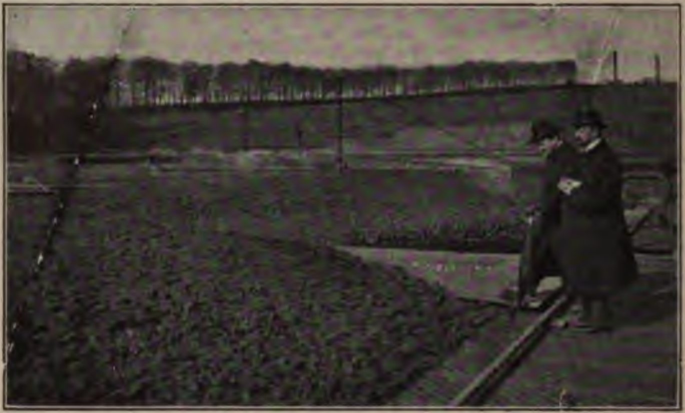


FIG. 101.—Whittaker and Bryant Sprinkler at Accrington.

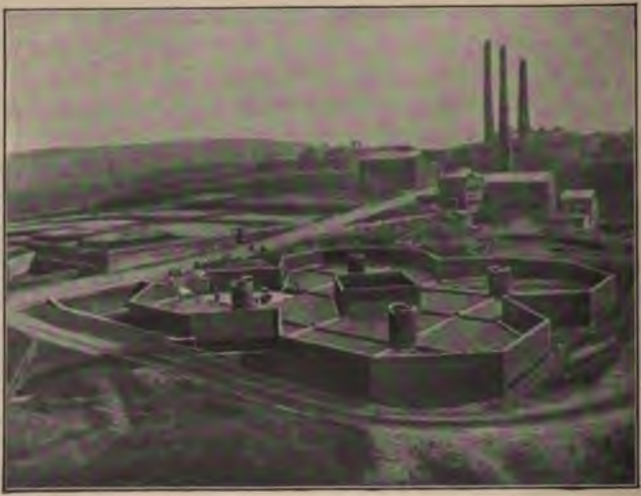


FIG. 102.—Whittaker and Bryant Biological Filters at Accrington.

but later, settling tanks had to be constructed in order to keep it from the stream.

The sprinklers at Accrington were supported on columns, as depicted in fig. 104. The friction surfaces were at the top of the columns, and at the bottom mercury seals were provided.

According to the experience gained in Leeds, a quantity of sewage less than about 225 gallons per square yard per day is not sufficient to keep Whittaker sprinklers in action, and the perforated pipes must be brushed out once a day, to prevent the holes from becoming stopped up.

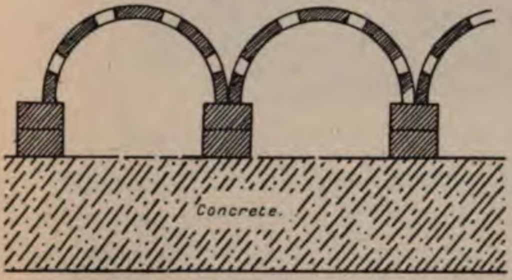


FIG. 103.—Aeration and Drain Pipes at the Bottom of Accrington Filter.

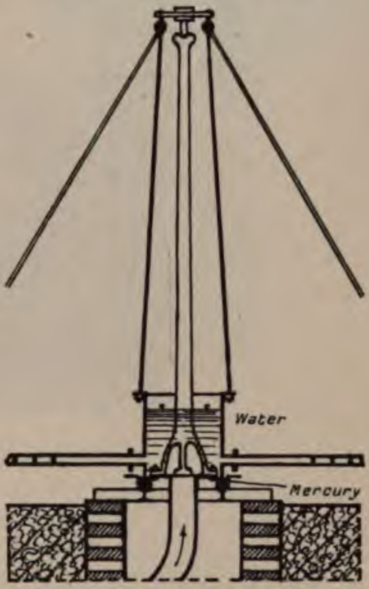


FIG. 104.—Accrington Sprinkler. Mercury Seal.

Candy-Caink Sprinkler.—The sprinkler constructed by Candy-Caink at Reigate differs from the preceding one materially in that a vessel is provided at the junction of the two distributing arms (fig. 105). This vessel is quickly filled with sewage, and then empties itself gradually through the holes in the sprinkler arms. The sudden filling of the vessel enables the sprinkler to be worked with a less head of sewage than would be possible with

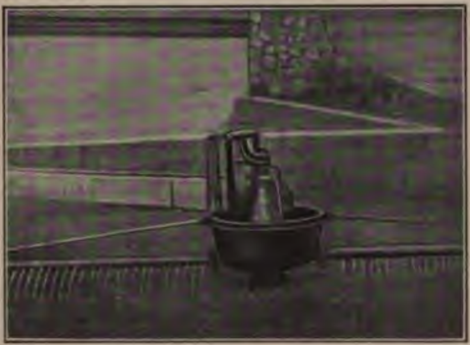


FIG. 105.—Candy Sprinkler at Reigate.

continuous action. The apparatus which interrupts the continuous action is depicted in fig. 106. A vessel connected by means of a lever with the valve admitting the sewage to the vessel of the sprinkler is so arranged as to fill with sewage in a definite time and thus to gain sufficient weight to raise the lever and open the valve. According to the volume of sewage to be treated, the apparatus can be arranged to revolve the sprinkler for one minute and to rest for two minutes, or to revolve for two minutes and rest for four minutes, etc. A disadvantage of this apparatus is that a certain volume of sewage is discharged at one point each time before the sprinkler is brought into action, and that the motion is more sudden than with the continuous, evenly rotating Whittaker sprinkler. In a form which was evolved somewhat later, Candy sprinklers have been adopted by a large number of English towns.

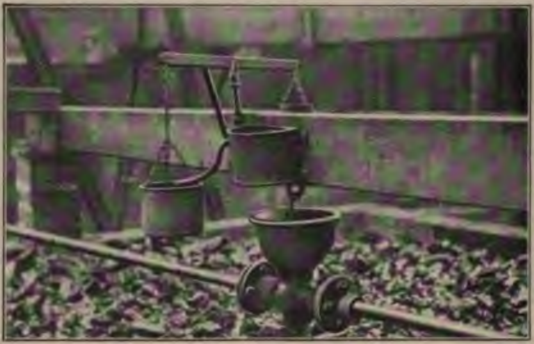


FIG. 106.—Apparatus for Feeding Candy Sprinkler intermittently at Leeds.

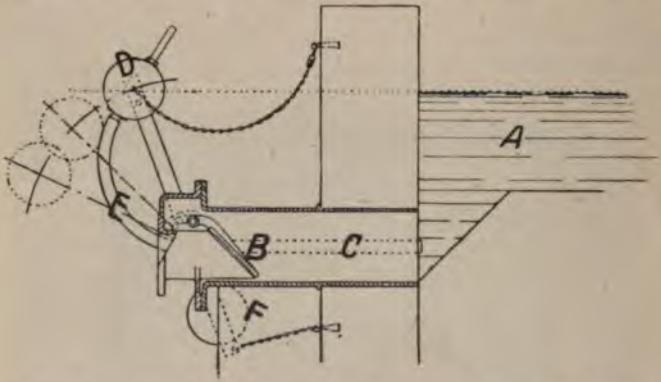


FIG. 107.—Apparatus for Measuring Charge and Feeding Sprinklers intermittently. Mather and Platt.

Mather and Platt's Sprinkler.—Mather and Platt have devised the *form of* apparatus shown in fig. 107, for the intermittent dosing of biological filters. The sewage collects in the measuring vessel (A) so long as the valve (B) is closed. Through the flexible pipe (E) the sewage enters the drum (D), which, when filled with sewage, becomes heavier than the weight (F). The drum (D) therefore falls, and opens the valve (B), thus admitting the sewage to the sprinkler. Mather and Platt were the first to replace the easily clogged perforated pipes by open troughs (fig. 108). The figure also illustrates the measuring vessel and interrupter. The drum is up, and therefore the measuring vessel is filling. As will be seen from the figure, the sewage is led in from the bottom, as in the Whittaker sprinkler. The rotation of the sprinkler is facilitated by the turbine shown in fig. 109, which is situated in the central portion of the sprinkler, and through which the sewage has to pass before reaching the open troughs. During the last few years Mather and Platt have constructed many sewage purification works, in which sprinklers have been adopted, feeding filters

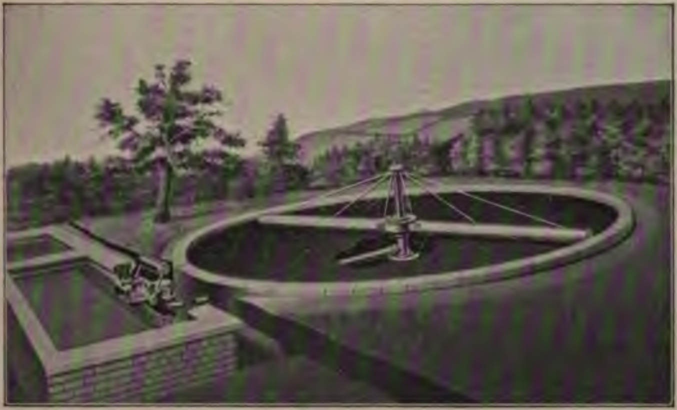


FIG. 108.—Mather and Platt Sprinkler, with Open Channels.

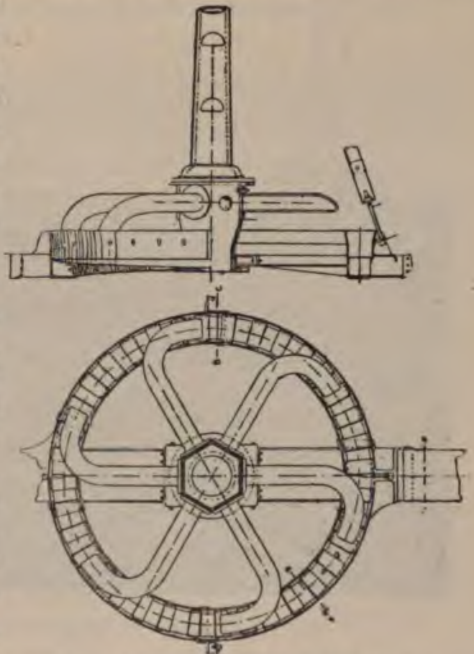


FIG. 109.—Mather and Platt Sprinkler, driven by Turbines.

from 14 to 207 feet in diameter. One of their larger forms of distributor, driven by electricity, is shown in fig. 110.

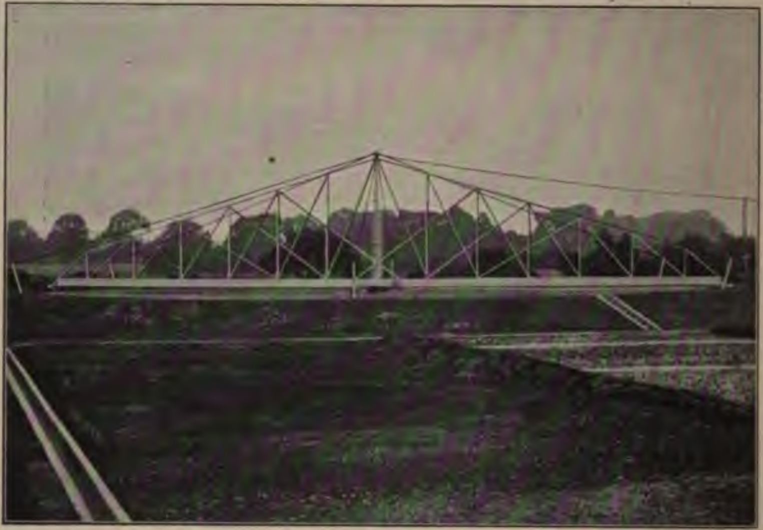


FIG. 110.—Mather and Platt Sprinkler, electrically driven (Chichester).

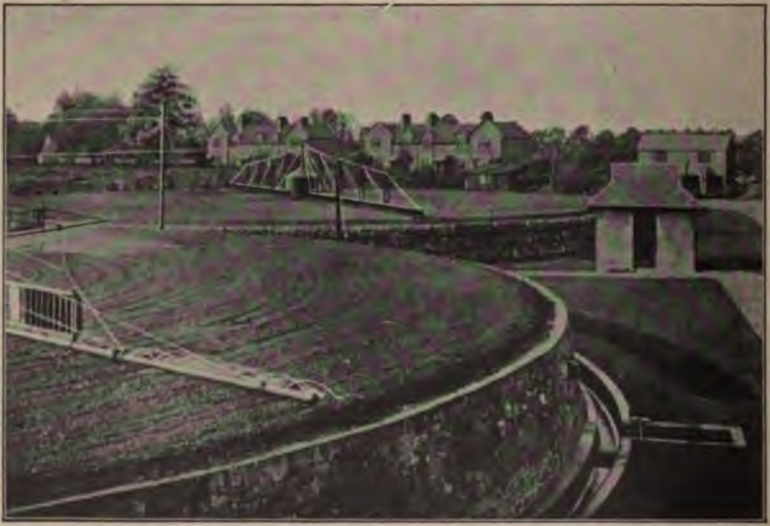


FIG. 111.—Birmingham Sprinklers.

In fig. 111 two of the large sprinkler filters are shown, which have been erected at Birmingham for the purpose of making comparative experiments. These also are driven electrically.

Jennings' Sprinkler.—In the form of sprinkler shown in fig. 112, constructed by George Jennings, Ltd., London, the sewage is led into a fixed vessel in the centre of the filter. The ends of the sprinkler arms dip into this vessel and syphon the sewage out. Another method of supporting and feeding sprinklers, adopted by Jennings, is shown in fig. 113.

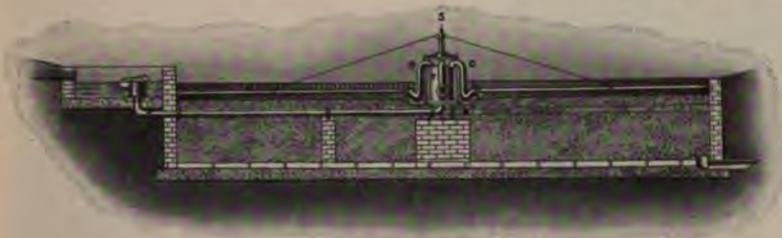


FIG. 112.—Jennings' Rotating Sprinkler, with Syphonic Feed.

Scott-Moncrieff's Sprinkler.—The large sprinkler shown in fig. 114 was erected at Birmingham by Scott-Moncrieff for experimental purposes. The sewage flows out of a movable open trough, and the sprinkler is rotated by means of a motor running on lines around the filter. The distribution obtained in this manner is very good, but the cost is said to be prohibitive.

Fiddian Distributor.—Quite novel was the idea of Fiddian to allow the sewage to discharge from cups into a distributing apparatus which had the form of an overdriven water-wheel (fig. 115). As soon as the grooves of the wheel become filled, the wheel rotates. In fig. 116 is shown a Fiddian distributor, fitted ready for the filling of the filter at Enfield. I have seen this distributor in operation, and at the same time two others in which the sewage was distributed by means of perforated pipes. The surface of the filters fed with perforated pipes was covered with a thick, grey, slimy, evil-smelling vegetation. At Leeds and other towns such vegetation considerably interfered with the purification of the sewage. On the Fiddian filter, which was fed with the same sewage and at the same rate as the other filters, this grey growth was absent, and in its place a green growth of algæ was noticeable, which had no smell. In all

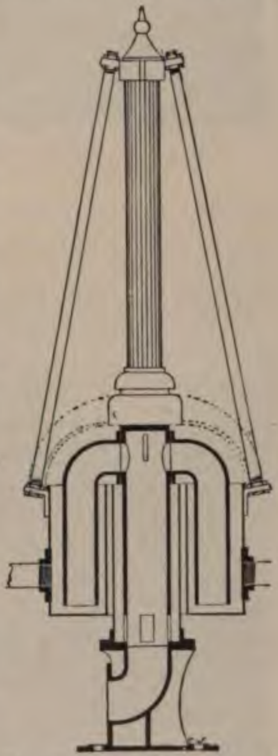


FIG. 113.—Method of Support for Jennings' Sprinkler.

three cases the sewage was derived from one and the same septic tank, so that the method of distribution alone could account for the variations in the growths on the surface of the filters.

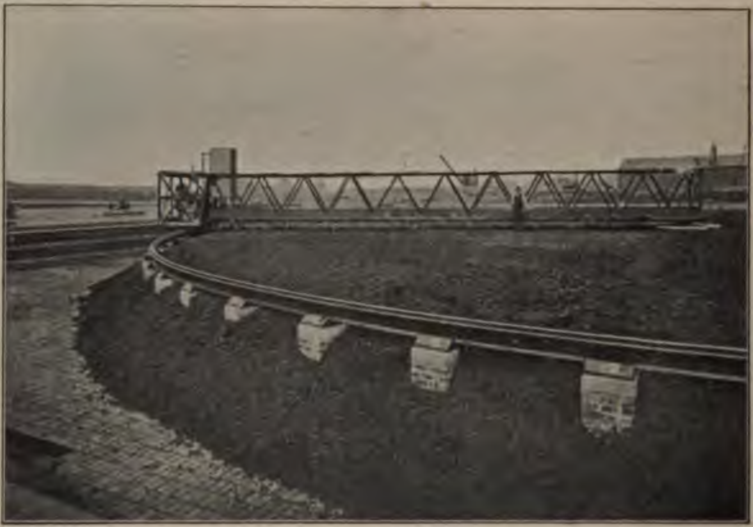


FIG. 114.—Scott-Moncrieff Distributor, motor driven (Birmingham).

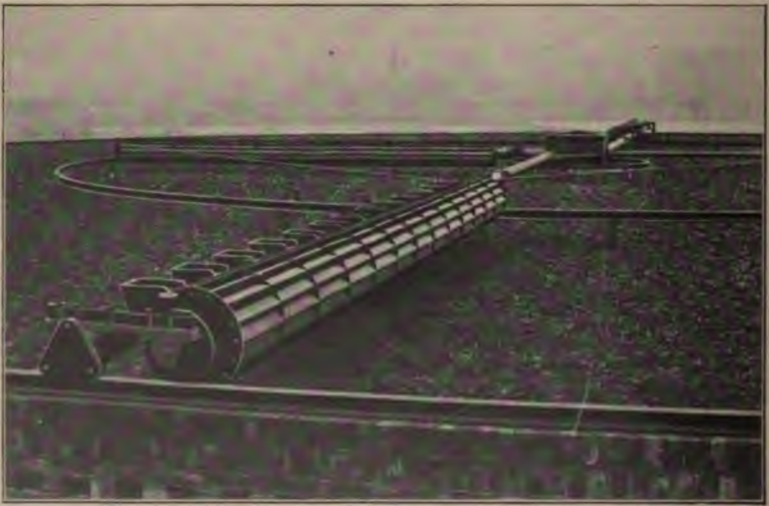


FIG. 115.—Fiddian Distributor (Enfield).

Fiddian distributors, which are manufactured by Birch, Killon & Co. of Manchester, are about twice as expensive as other forms of distributor. They have, however, quickly attained a good reputation, because, possessing no narrow holes likely to become clogged, the sewage can flow freely, because also of their reliability in working, the even distribution of the sewage, and for various other reasons.

Travelling Distributors.—In addition to rotating sprinklers, travelling distributors have lately been adopted for the purpose of feeding rectangular biological filters. The form shown in fig. 117 is moved backwards and forwards by means of electricity. The sewage is syphoned from the feed channel situated between the two filters and distributed by means of open troughs.

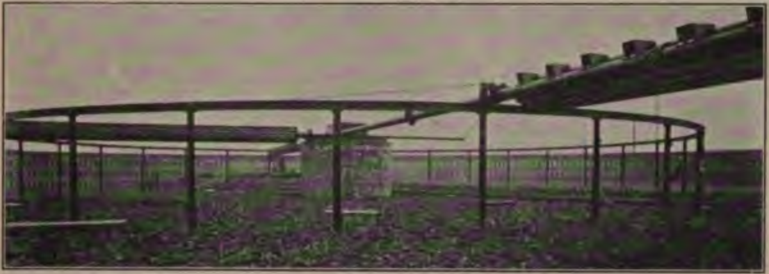


FIG. 116.—Fiddian Distributor, in course of erection.

Adopting the principle of the overdriven water-wheel introduced by Fiddian, Ham, Baker & Co. have constructed a travelling distributor at Bolton (fig. 118). The sewage is discharged from cups on to one side of the water-wheel, so that the apparatus moves in the direction towards these cups. As soon as the end of the filter is reached, a lever collides with a buffer (P, fig. 118), and causes the current of sewage to be deflected to a series of buckets on the other side of the water-wheel, so that the apparatus moves automatically backwards. I have seen the apparatus

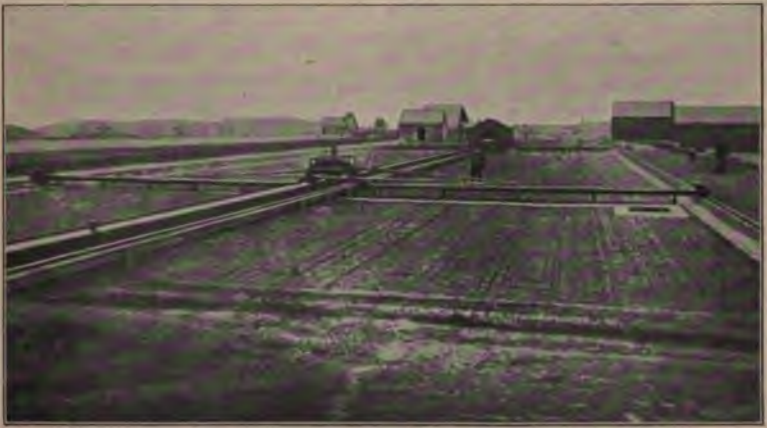


FIG. 117.—Wilcox and Raike's Distributor for Rectangular Filters, motor driven.

working at Bolton, and after several months working it was giving every satisfaction as regards the reliability of its automatic action. In the district, however, mining operations are carried on, with the result that the ground occasionally sinks and the rails have to be levelled afresh.

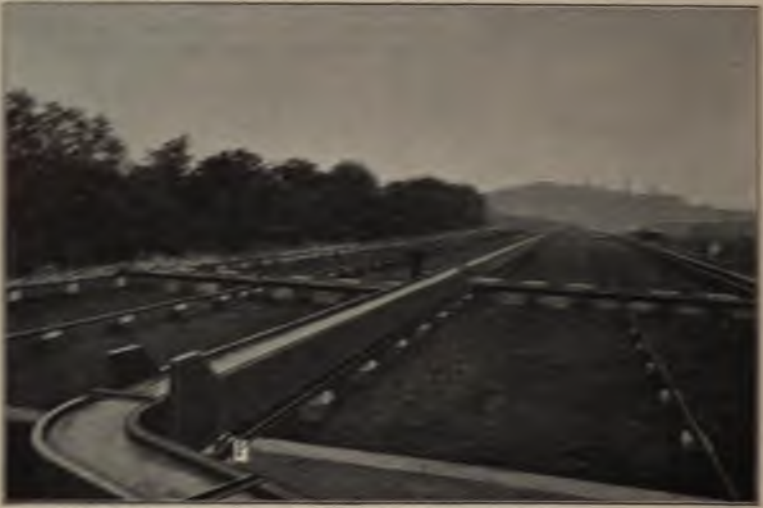


FIG. 118.—Ham, Baker & Co. Distributor. Fiddian's Principle applied to Rectangular Filters (Bolton).

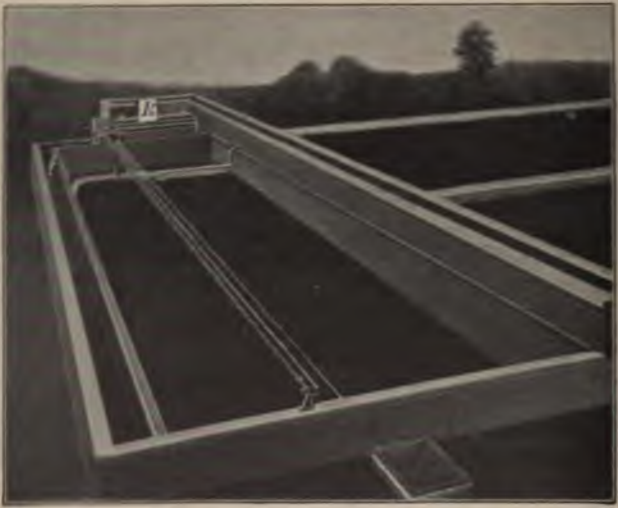
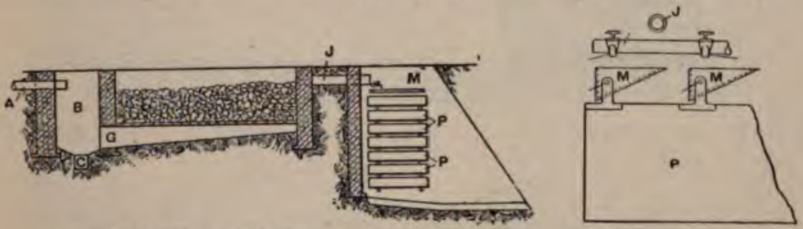


FIG. 119.—Jennings' Distributor for Rectangular Filters.

Jennings also works a travelling distributor by means of a water-wheel (R, fig. 119).

Scott-Moncrieff's Method of Distribution.—At this point, for the sake of completeness, a method of distribution should be described, of which much has been heard. In 1891 Scott-Moncrieff constructed his cultivation tank (see p. 96), *i.e.* a tank filled with stones (fig. 120). The sewage enters by the pipe (A), passes beneath the perforated bottom of the tank (G), and upwards through the tank, leaving the undissolved solids and discharging through the pipe (J) on to the tipping apparatus (M), which throws the sewage on to the surface of the coke (see also fig. 121). The sewage then drops gradually through the trays (P). The apparatus has been adopted for various private houses, barracks, and similar institutions.



Figs. 120, 121.—Scott-Moncrieff's Cultivation Tank and Biological Filter.

Ducat's Filter.—The filter invented by Ducat has also received much attention and deserves mention here (fig. 122). The walls of the filter are composed of drain-pipes placed nearly horizontally, with the object of effecting aeration from the sides. In order to restore the consequent loss of heat, the filter is provided with a heating apparatus. The sewage is distributed over the surface of the filter by means of tipping troughs. The filter is constructed in various layers, as shown in fig. 123.

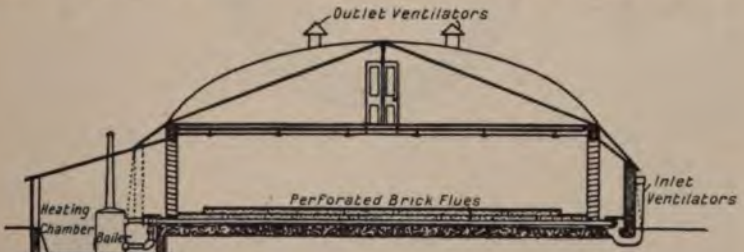


Fig. 122.—Ducat's Biological Filter, with Heating Arrangement

Sprayers. — Corbett has adhered to fixed sprinklers, which he has gradually perfected, finally adopting a form in which the sewage is sprayed in the form of a fountain. For a time he used the jet depicted in fig. 124, which sent a sheet of sewage over the surface of the filter, as shown in fig. 125. This method of distribution has given every satisfaction at Salford, and it has been adopted by Watson at Birmingham on a very large scale. Watson has adopted the form of jet shown in fig. 126. In the centre it carries a nail (A), which can be taken out and replaced if the jet shows

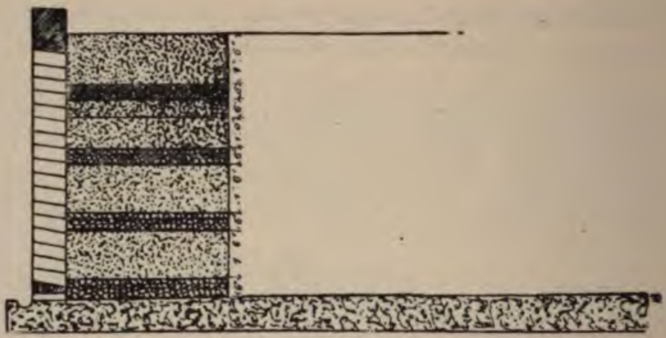


FIG. 123.—Ducat's Biological Filter, showing Method of Aeration and Grading Material.

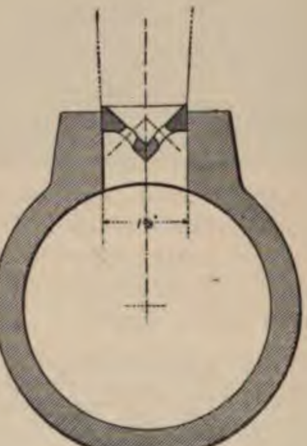


FIG. 124.—Gjers and Harrison Spray Jet, as used by Corbett at Salford.

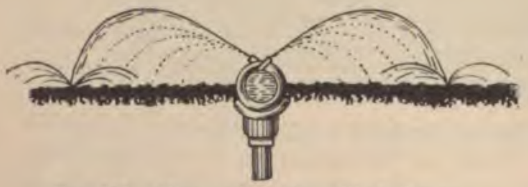


FIG. 125.—Gjers and Harrison Fixed Spray Jet in Action.

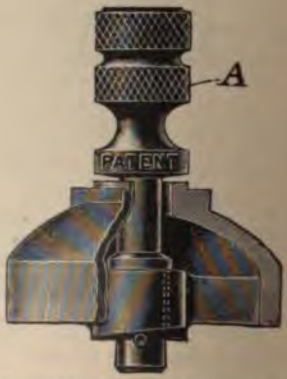


FIG. 126.—Ham, Baker & Co. Sprayer at Birmingham.

signs of bad distribution. A Birmingham filter is shown in cross-section in fig. 127, and in perspective in fig. 128. The well-known engineers Fuller and Hering have also adopted fixed spray jets at the Columbus Experiment Station, after making comparative experiments with all suitable methods of distribution; these were adopted in view of the severe

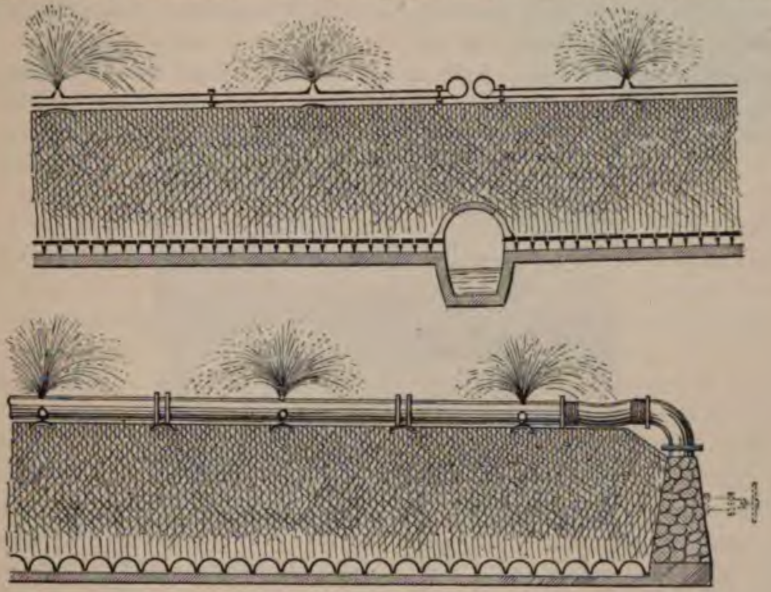


FIG. 127.—Birmingham Filters. Cross Section.

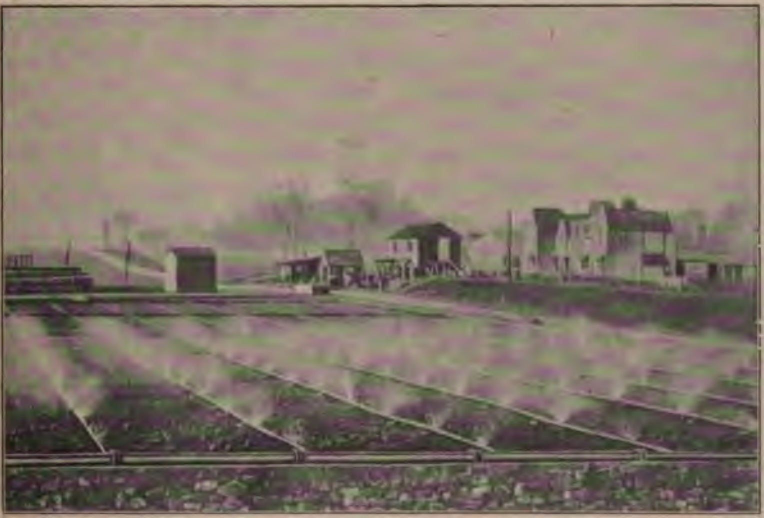


FIG. 128.—Birmingham Filters. Bird's-eye View.

frosts which occur in the United States. A filter, fitted with a spray jet, is shown in fig. 129, as it was seen by Winslow in winter. The filter was covered with ice and snow, and yet surrounding the spray jet the heat of the sewage was sufficient to keep the surface of the filter free, even under the difficult circumstances depicted. On this account Hering and Fuller have recommended the adoption of these spray jets at Baltimore. They use the Columbus sprayer, shown in fig. 130. The sewage passes freely through the jet, and then is forced against a cone, which distributes it in the manner illustrated by fig. 131. Clogging of the jets, such as occurs at Birmingham, chiefly on account of grease deposition, is said not to occur with the Columbus sprayer. Through the kindness of Franze of Leipsic, I have received a Columbus sprayer, but experiments which I have carried out on the evenness of the distribution have not been quite satisfactory. This fault is acknowledged by G. W. Fuller, but it is intended to be overcome at Baltimore by first collecting the sewage in tanks which are to be emptied intermittently in the manner described on p. 199. In

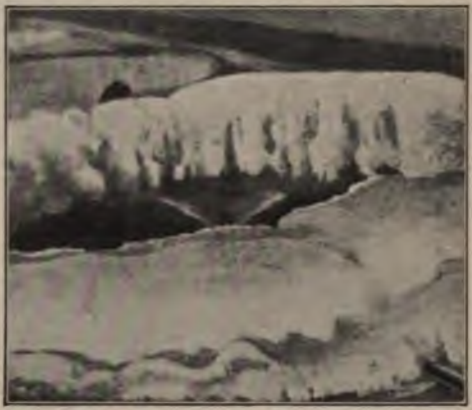


FIG. 129.—Columbus Sprayer in Winter.

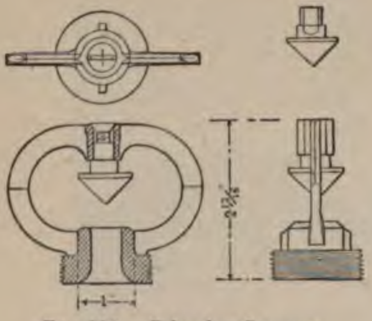


FIG. 130.—Columbus Sprayer.

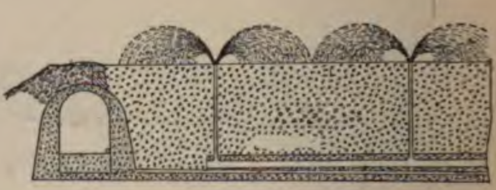


FIG. 131.—Columbus Sprayer in Action.

this manner the pressure on the jets will be varied, and a more even distribution consequently obtained.

In the meantime I have had other forms of sprayers submitted to me, but these will not be described here, especially as they do not meet all the difficulties which present themselves in spraying sewage. They will be described, however, along with other recent improvements in the technical details of sewage purification, in the pages of the *Gesundheits-Ingenieur*.

Importance of Fine Surface Layers.—It has already been mentioned that the Accrington filters yielded at first perfectly clear effluents, but that these gradually became turbid and deposited peaty matter. As time went on these flocculent deposits became more serious. The deposits were largely non-putrescible and very stable. From this it was concluded that it was necessary for this material to be washed out of the filter, for fear of clogging the pores. Especially from Leeds the recommendation was made to construct biological filters of such coarse material that this flocculent matter could pass freely away. Such procedure is, to a certain extent, justifiable, but it should first be asked whether the amount of these deposits cannot be diminished. Their nature, therefore, should be first investigated. They consist of the products of weathering action on the material of which the filters are constructed; of the more stable residue of the organic matters in the sewage, which have been deposited either mechanically or by means of absorption on the filter material; of ferric hydrate, derived partly from the sewage and partly from the clinker, coke, etc.; and, finally, of animal and vegetable forms of life.

In my opinion the quantity of these substances may be regulated by constructing the surface of the filter of fine material, so as to retain the greater portion of the suspended solids and of the absorbable solids in solution, either on or immediately beneath the surface of the filter. Against such a method we have the observation that even with filters constructed of very large material, such as those at Leeds, the sewage began to pool on the surface as soon as the growth of *Pilobolus* reached a certain intensity. It was thought that the character of the Leeds sewage was specially favourable to this growth, but it has already been mentioned that at Enfield two filters showed a large amount of such growths on the surface, whilst another showed none, according to the method of distribution of the sewage. According to my own observations, such growths are more favoured in cases where the sulphuretted hydrogen is retained in the sewage until it reaches the filters, as in all cases of distribution by means of perforated pipes, than when the effluents from septic tanks are first aerated to some extent. I have made observations on a percolating filter constructed of very coarse material, and on which this fungal growth was very marked indeed. On using a fine surface layer the fungal growth did not interfere, although the same sewage was applied to the filter. I am convinced that this result was not merely due to the method of distribution, but largely to the action of the fine material.

14

My experiments on this point date from 1902. In 1904 Reid began to use fine material at Hanley for the surface layers of filters, and the results which he has obtained have been satisfactory. It has been stated that these results are due to the fact that the Hanley sewage is a very weak sewage. The character of the sewage may have had a certain importance; but my own observations with very concentrated sewages, such as that of Unna, have convinced me that the method will give satisfactory results with sewages other than those which are very dilute.

The importance of fine surface layers will be referred to again shortly; but before doing so, I should like to draw attention to the fact that the opinion generally held is that percolating filters should be so constructed that the flocculent matters can be readily washed through with the effluent. At Leeds it was considered advisable to facilitate this, either by means of a hose-pipe or by dosing the filter temporarily at a high rate. Microscopical examination of the substances thus washed through reveals the presence of much animal and vegetable life, and chemical analysis shows that the products of the weathering action on the material of the filter are also present. In order to limit weathering action, the use of very resistant material, such as broken saggers (waste from the potteries at Hanley), broken granite (Birmingham), and pebbles (Rodley, Leeds), has been gradually adopted for the construction of percolating filters.

In well-aerated percolating filters the weathering processes are not so intense as in contact beds. Even when cinders are used, the life of a percolating filter is longer than that of a contact bed, but coke is not to be recommended, because it will not bear the weight of the upper layers without breaking down.

In England, almost without exception, percolating filters are dosed with septic sewage. This has occasionally given rise to complaints of nuisance from smell. At the present time the Royal Commission is having experiments carried out to see whether such nuisances can be avoided, and at the same time a larger volume of sewage treated on percolating filters, by subjecting the sewage to a preliminary chemical treatment. In this direction the experiments will be very valuable which are being undertaken to see whether chemical precipitation will not admit of filters, designed and constructed for the dry weather flow, being used in wet weather for three to six times this quantity.

From what has been said, it will be seen that during the last few years rapid progress has been made both with respect to the distribution of sewage and the construction of percolating filters. It may be said that the percolating system has almost driven the contact process out of the field. Of the large towns, with the exception of Manchester, where the contact process had been adopted before the percolating system had received general recognition, Sheffield alone can be mentioned where the contact process is being adopted.

***The Hamburg* Filter System.**—A few years ago I expressed myself sceptically regarding rotating and movable distributing apparatus. Practical experience has proved the correctness of my views; for wind, frost, and other causes, especially damage to the bearings of the apparatus, have interfered with the distribution, and thus with the purification of the sewage. In the more modern forms described above, such faults have been overcome; but, in spite of this, a method which I worked out in 1901 still possesses some practical importance.

The Hamburg Filter with Fine Surface Layer.—In 1901 the artificial biological method of sewage purification had been so far developed as to justify its adoption by any town or large institution. Difficulties were chiefly met with in small works, such as those for private residences or small institutions, where there was nobody to look after the works. In such cases the contact process could not be considered, since it requires very careful attention and soon shows the effect of neglect, the beds and consequently the effluents becoming putrescent. The adoption of automatic feed and distributing apparatus would also have required attention and supervision, for any stoppage in the working would have allowed the sewage to flow unpurified through the beds. At that time I was asked for advice almost daily from various quarters as to the best method of procedure in such cases. I was engaged upon experiments with a view to collecting the sewage in tanks, and syphoning it over on to biological filters, the outlet from which was always kept open. The result of the experiments exceeded my expectations. Stoppages in the comparatively narrow syphon tubes could be easily avoided. In spite of this, I have never recommended the adoption of such a method in practice, for it was evident that the syphon would become stopped up if neglected, and experience has shown that such neglect must always be taken into account. The resulting consequences would have been attributed to artificial biological processes generally, and at that time their practical applicability was being very much questioned in many influential quarters.

I placed the problem before myself somewhat as follows: The works would have to be placed in such a position as neither to be seen nor smelled, and so that they would work without any attention for days at a time. Hence at no point would the flow of the sewage have to be hindered by narrow pipes or similar obstacles. As a rule, no very large fall is available, and hence the filters, etc., would not have to be very deep. Finally, the works would have to be carried out at a low cost.

The observations which I had made in the syphon experiments led me to the following considerations and experiments: If sewage is placed upon a layer of fine material, it can only pass through at a fixed maximum rate. If layers of material, gradually increasing in size, be placed beneath the fine material, the sewage which has passed through the upper layer will be taken up by the lower layers in the form of drops, each piece of material drawing the liquid from the finer material immediately above it. The liquid then spreads over the separate pieces of material, and collects at the bottom or on projections in the form of drops, which fall on to the next lower piece of material, where the same process is repeated. On the smaller pieces of material the process is not easily visible, but on cinders the size of one's fist the formation of drops can be observed on each projection. In the very coarse material the drops fall from one projection to another through the intermediate air space, and this process takes place throughout the filter. It was easily observed with models which I had constructed, about a yard high and about a foot in diameter.

The even distribution and resolution of the sewage into the form of drops could thus be attained in a very simple manner, quite as well or even better than by means of the above described expensive forms of apparatus. Without any form of apparatus, therefore, not only can definite quantities of sewage be put through the filter, but this can be distributed throughout the filter as evenly as can be desired. In my experimental filters all the coarser suspended solids remained on the surface of the fine top layer of material. In this layer also the greater part of the dissolved substances were retained by absorption, and the liquid passing into the lower layers was nearly clear and only slightly putrescible. A sample of the liquid taken immediately below this layer still contained considerable amounts of ammonia, but only small quantities of nitric acid. In the lower layers the reverse was the case, and even when very strong sewage was employed, the effluents were perfectly clear, colourless, and free from smell.

Biological filters in walled tanks or fermentation vats, which had for some time given good results, ceased to do so when covered with a layer of fine material. Even with filters which had previously given excellent results when worked intermittently, the effluents soon commenced to smell of sulphuretted hydrogen and to become black. This state of affairs was not improved by inserting comparatively wide ventilating pipes through the surface into the coarser layers. Later, as we shall see, I learnt how to obtain good results from filters constructed in walled tanks beneath the surface of the ground and entirely covered in. My experiments were first developed on biological filters which had previously been used as contact beds, and which were constructed of cinders, 3 to 7, 5 to 10, and 10 to 30 mm. in size. Furrows were dug on the surface of these beds and filled with fine-grained material. These facts are given in chronological order, in order to prevent others in future from making mistakes which have repeatedly been made in constructing works on this simple principle, and also because quite erroneous ideas have been prevalent as to the origin of this method.

The surface of the beds was not prepared as at Manchester, where the method adopted has not given satisfaction, but with the observation of certain necessary precautions, to be detailed later. Between the various furrows the coarse material was visible for a width of a few inches. When the sewage was led into the furrows, filled with fine material, better effluents were obtained than had previously been obtained from the same filters working as contact beds; at the same time more sewage could be treated during the twenty-four hours, although the filters were only operated for twelve hours, resting at night. The new method possessed the advantage over the contact process in that the works required no attention through the day. The sewage flowed into the furrows throughout the day, and had a free outlet from the bottom of the filter. It was not necessary to be continually opening and shutting valves throughout the day, as with the contact process. Besides this, more sewage could be treated and better effluents obtained.

The results obtained up to this point were so satisfactory that I decided to recommend the adoption of the new method in two cases, where contact beds had proved a failure. In one of these cases (fig. 132) the contact beds were constructed, about 6 feet deep, of clinker 3 to 7 mm. in size, and treated with septic sewage. The effluents were black, and smelled of sulphuretted hydrogen, because under the existing conditions there was not sufficient exchange of air. The beds remained just as they were; the surface alone was furrowed and treated as above described. The result was immediately evident; the effluents were well purified and contained large quantities of nitric acid. The incoming sewage could easily be dealt with.

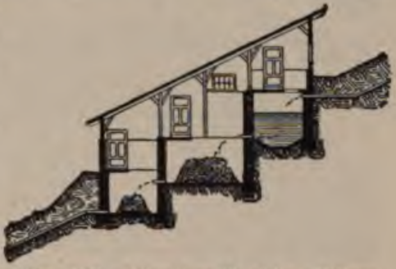


FIG. 132.—Hamburg Trickling Filters (Andreasberg).

In the second case the sewage was from a tannery. Attempts at treatment in contact beds had failed, because, on account of the large amount of organic matter which the refuse contained, when it was run on to the beds it formed a foam on the surface as much as two yards high, and this prevented access of air. Furrows were dug on the surface of the beds and the sewage allowed to enter in a steady stream. No foam was formed, the purification was improved, and all technical difficulties in operating the works disappeared.

In 1904 Calmette evolved a method at the Madeleine Experiment Station, which is very similar to mine at this stage of its development, except that he employed the method of feeding the filters which I had in the meantime abandoned, *i.e.* by means of syphons (fig. 133). Calmette was satisfied with the working and the results obtained from these filters.

I was not quite satisfied with my system of furrows, because a filter constructed on this principle could not be left entirely to itself. If the furrows were to become clogged, or the sewage were suddenly applied in large volumes, the sewage would overflow into the coarser material of the ridges. There was also a danger that sludge and fine material would be raked into the exposed coarse material when raking over the furrows, thus causing a clogging of the pores and consequent interference with a proper exchange of air. I therefore constructed a biological filter of clinker the size of a man's fist and larger, in the form of a truncated pyramid, and on the top of this I placed fine material, graded as described later. The fine material was held in position by a hollow cylinder of metal, which at the same time prevented the sewage overflowing. Septic as well as fresh sewage when placed on such a filter was discharged from the very beginning as a clear, colourless, and non-putrescible effluent, containing nitric acid in such quantities as we had never previously obtained from the same sewage at our experimental works. Per square yard of surface the amount of sewage treated on this filter about four and a half feet deep, per day of twelve hours, was 270 gallons, equivalent to 200 gallons per cubic yard of clinker. Side aeration alone must have accounted for this increased qualitative and quantitative efficiency. From this date onwards I have therefore had these filters constructed without side walls whenever possible.

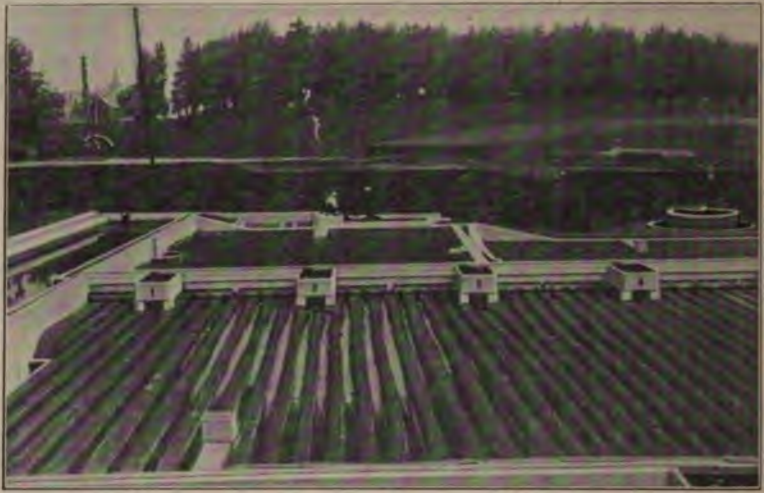


FIG. 133.—Calmette's Filters (Madeleine).

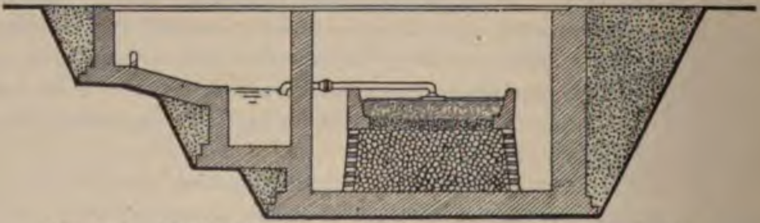


FIG. 134.—Hamburg Trickling Filter (Gross-Hansdorf). Cross Section.

Such a plant is illustrated by figs. 134 and 135. It is entirely situated below the level of the ground, and the beautiful park-like estate on which *it has been* built is not in any way disfigured by it. The effluent flows into a small pond, where it has left no traces of its presence, although the works have been in operation for some years.

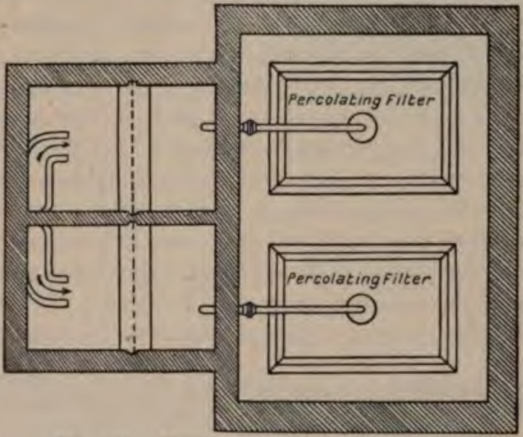


FIG. 135.—Hamburg Trickling Filter (Gross-Hansdorf). Plan.

The following may serve as an example to show the futility of dealing with all questions of sewage treatment according to a common plan: Irrigation is rightly regarded as the best method of sewage purification, and therefore it was going to be adopted for a convalescent home. In the case to which I refer very suitable land had been bought for irrigation purposes, but the home itself would have been surrounded by irrigation areas. On my advice, therefore, irrigation was abandoned in favour of artificial biological treatment. Local circumstances were such that it was only possible to construct works in the immediate vicinity of the home, but it was possible to place them in an outhouse indicated by a cross on fig. 136.

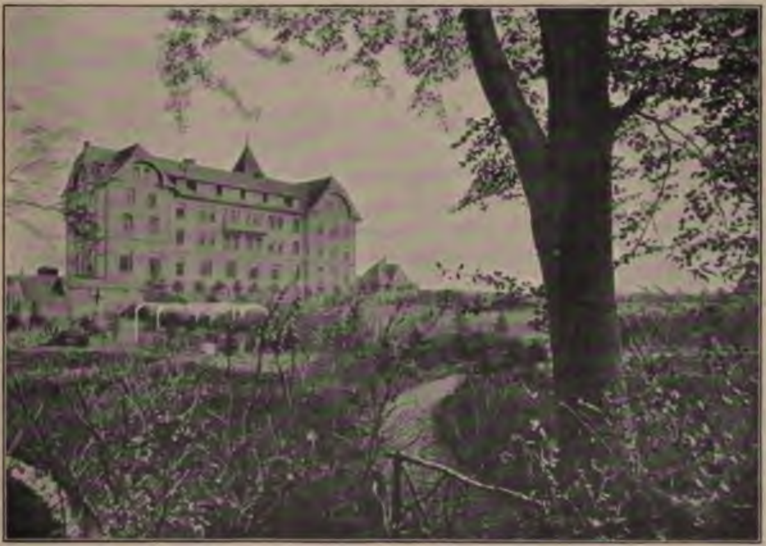


FIG. 136.—General View, showing Comparative Size of Biological Sewage Works for a Sanatorium.

The building is entirely hidden by the bushes close to the large institution, which is now therefore situated in a beautiful park, instead of in the middle of a sewage farm. In the six years during which the works have been in operation, no nuisance whatever has been caused. The works were constructed under the direction of the eminent director, Gebhard, whose early decease is to be greatly lamented. The various other similar small works which have been constructed on his initiative have all worked very satisfactorily. If these results are compared with the numerous unsuccessful results which have been the fate of biological processes in Germany, it is clear what a very important place is to be assigned in such matters to personal influence and a knowledge of humanity. Gebhard always understood how to find the most suitable people for the work which was under his direction. The first attendant whom he selected was very sceptical and had no faith in the biological method. After he had become convinced, against his will, of the utility of the method, he was a very warm supporter. Later he was entrusted with the first working of the various other works mentioned.

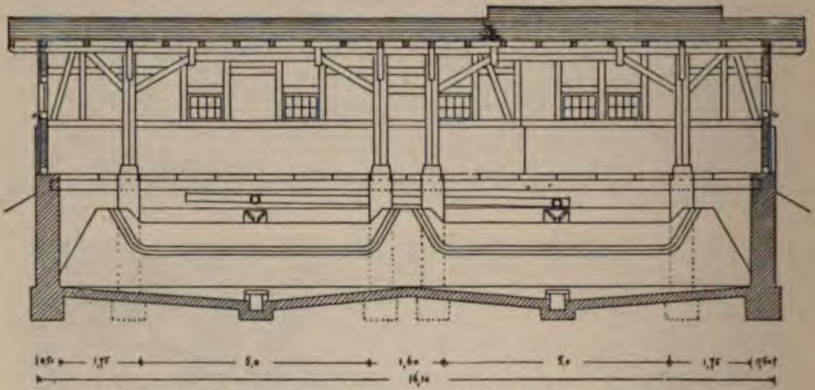


FIG. 137.—Hamburg Trickling Filter (Oderberg). Cross Section.

Whilst the Gross-Hansdorf works, as we have seen, could be constructed entirely below the level of the ground, the works illustrated in figs. 137 and 138, designed by the architect Sartory, had to be constructed above the ground level, and, in view of the severe mountain climate, they were covered in. The two drawings explain themselves without further description.

As I have already stated, my earlier experiments with fine-graded material were undertaken with the object of devising biological filters requiring little attention and thus suitable for private residences. I began by constructing septic tanks on the principle of the *Fosses Mouras*, and in these the sewage was made as strong as possible by the introduction of considerable amounts of fæcal matter and waste vegetables. When a gallon of sewage reached these tanks, a gallon was expelled on the other side. In experimenting, all the irregularities which may be expected in a household were imitated; two gallons of sewage were introduced, corresponding to the emptying of a bucket; then again about fifty gallons corresponding to the emptying of a bath. The tank had a capacity of about 450 gallons, and received about 150 gallons of sewage daily. The effluent from this septic tank had a very penetrating odour of ammonia; that from the filter was clear, with a slight yellow tinge. It had an earthy odour, and contained from 4 to 10 parts of nitric acid per 100,000. When kept in closed bottles, no objectionable gases were produced. The filter in question was only three feet deep, in order to be applicable in cases where little fall is available.

In order to test whether the septic tank was necessary, sewage to which considerable quantities of fæcal matter and kitchen refuse had been added, was fed on to a percolating filter in the same irregular manner as above, without, however, being allowed first to become septic. The filter was small, and could only deal with about forty-four gallons at a time. A collecting tank was therefore placed to receive the sewage before reaching the filter, the outlet of the tank being closed by a float valve as soon as the sewage pooled on the top of the filter. A basket was placed beneath the outlet pipe from the tank, in order to retain the coarser suspended solids. In this case also the effluents were satisfactory.

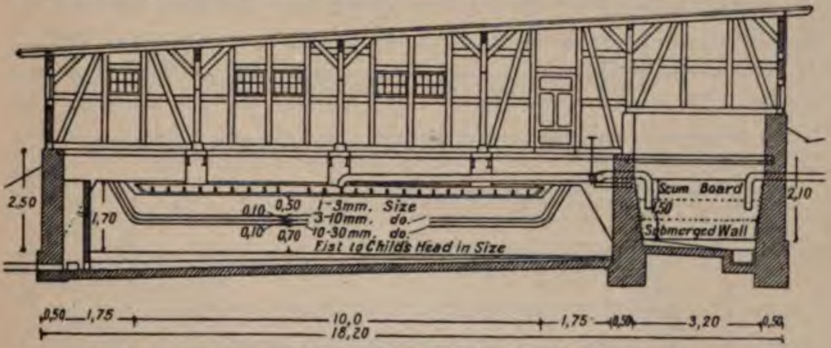


FIG. 138.—Hamburg Trickling Filter (Oderberg). Longitudinal Section.

In accordance with this experiment, works were constructed for a house with thirty inmates. They were placed entirely underground, so that nothing was visible except the three covers shown in fig. 139. The filter was constructed of clinker. Air was admitted to the filter on one side through the open brickwork and also at the sides of the surface layer. The effluent was treated on a second small filter before being discharged to a road-side ditch. When the sewage was conducted directly on to the first filter, clogging soon took place on account of sand, which was contained in large quantities in the sewage of this country mansion. A detritus tank containing a nearly vertical screen was therefore provided, and in the four years during which the works have been in operation neither clogging nor any other fault has occurred. As soon as the surface layer shows signs of becoming impervious, usually after about a week, the sewage is discharged for a day direct to the second smaller filter. The larger filter then dries and is raked over. The filter easily accommodates itself to the considerable variations in the volume of sewage. The deposit in the detritus tank is occasionally shovelled out and buried in the garden. The plant is really one which requires so little attention and which has been constructed so cheaply that it could easily be accommodated on any private estate.

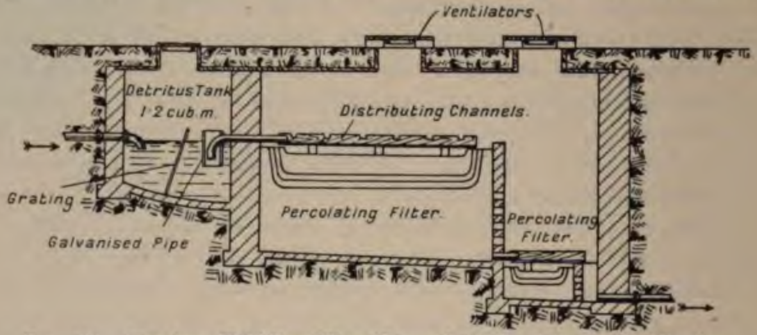


Fig. 139.—Hamburg Trickling Filter (Poppenbüttel). Longitudinal Section.

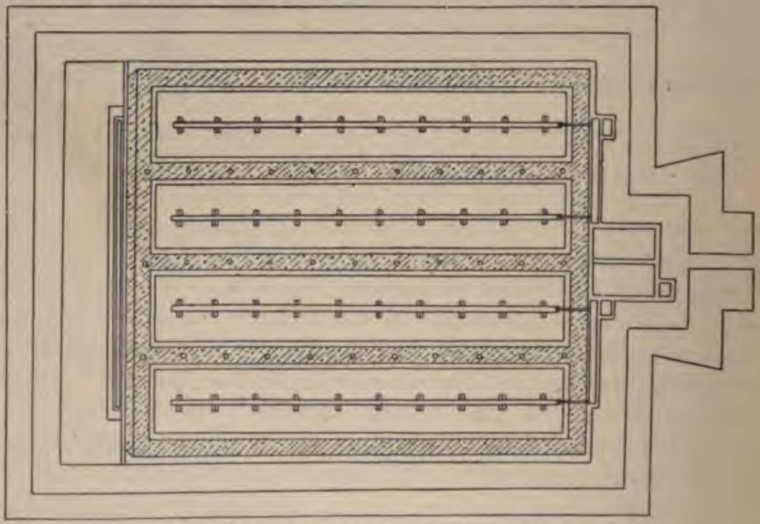


Fig. 140.—Large Hamburg Filters. Plan.

In 1902 I had already gained such confidence in this method that I was able to advise the town of Unna upon its adoption. The works had to be constructed for a population of 10,000, and the sewage is more concentrated than that of any other town of similar size, owing to the effluents from breweries and a grain-washing plant. The Unna filters were *designed* and grouped together like those illustrated by fig. 140, except that the feed pipes were situated on the same side of the filter as the effluent channel. The bed and sides of the excavation were simply covered loosely with brickwork, the soil being possessed of sufficient supporting power. The base of each filter was inclined towards the centre, so that the purified effluent flowed towards an effluent channel situated at this point. The effluent channel was situated as low as possible and covered with cement flags placed at such distances apart as to allow free entry and exit of air. The bottom layer of the filter was composed of pieces of clinker, a foot or even more in diameter. Between each two filters a wall (fig. 141) was built up of very large-sized clinker, to serve not only as a support for the filters, but also for purposes of ventilation. The filter within the clinker walls was constructed of material as large as a man's fist, which was forked into the filter so that the finer material was left behind. A layer of this finer material, about the size of walnuts, was placed over the coarser material, and then on the surface, between the clinker walls, beds of fine material were constructed (fig. 141). The sewage was distributed from slightly inclined V-shaped troughs, passing down the middle of each filter.

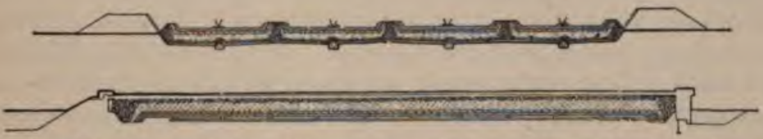


FIG. 141.—Large Hamburg Filters. Cross Section and Longitudinal Section.

These works have come up to and considerably exceeded my expectations. The original scheme provided for a secondary set of filters; but on my advice it was decided to first construct the primary filters, and in such a manner that the effluent could be discharged by gravitation to secondary filters, should these prove necessary. The works have been in operation since 1903, the separate filters being brought into operation as soon as completed. Portions of the separate filters can be brought into or left out of operation according as ridges of the fine surface material are omitted or constructed. I have repeatedly had opportunities of convincing myself that the effluents from the Unna filters are never putrescible, although the works have been continuously dealing with larger quantities of sewage than they were designed to treat. Only recently have sufficient filters been constructed to deal with the increasing volumes of sewage.

A description of the Unna works is contemplated by the city engineer, Modersohn. It may be mentioned, however, that the cost of constructing the works, exclusive of the price paid for the land, amounted to six shillings and threepence per head. If the sewage had not contained trade refuse, the works need only have been about half the size; and the filters, which were originally constructed rather deeper than necessary as a precaution, since only little experience had been gained at that date, need not have been constructed quite so deep. The later filters have been made shallower and yet work more satisfactorily than the earlier ones, because greater experience had been obtained as to their working.

During recent years my system has been adopted by several other towns. Mistakes have been made which would scarcely have been thought possible with such a simple process. It is unnecessary to describe all these works in detail, but the mistakes which may be made will be dealt with later.

At the present time, Bad Harzburg is constructing works on this system for a population of 10,000. The sewage is domestic in character, and comparable with normal town sewage. In the construction of the works, which are nearing completion, great care is being bestowed on every detail, and they will afford valuable information as to the capability of the filters. That, even under the most adverse conditions, the filters, when properly constructed, will yield satisfactory results, has been shown by the Unna works.

Engineers are not always able to carry out their projects as clearly and simply as in the above cases. Repeatedly there is a tendency to introduce pumps, large aerating shafts, ornamentation of the distributing channels, and other matters which are not only perfectly useless, but which also endanger the satisfactory operation of the works, or at any rate considerably increase the attention necessary. In the biological method the primary considerations deal with physical, chemical, and biological processes, and technical details as to the solution of the problem are of secondary importance. Among the latter the first place should be given to simplicity of construction and easy supervision.

The whole secret of my process lies in the proper selection and arrangement of the surface layer. My first experiments were carried out with sand and gravel, then with garden soil, but clogging soon took place, and the surface became impervious to the sewage. This only confirmed a fact which had been known for decades. The clogging of sand can only be avoided by working the filters intermittently, and allowing the surface of the filters to rest for two or three days after each charge. Better results were apparently obtained by the use of flue dust, which absorbed the sewage like a sponge and distributed it in drops over the lower layers. The flue dust, however, formed a paste with the sewage, cracks were formed, and the sewage then fell directly through without being purified. Coke and clinker have yielded very satisfactory results. If the dust is allowed to remain along with the broken clinker, only very small quantities of sewage can pass through, but these show a much higher degree of purification than should ever be necessary. If the surface layer is composed of too coarse material, the sewage simply falls through without being properly distributed. A mixture of fine and coarse material should not be employed, for the finer lodges in the pores of the larger. The best results have been produced by the use of material carefully sieved so as to contain nothing less than 1 mm. nor greater than 3 mm. in size. If such material is placed directly on to coarse clinker, it is simply washed in, with the consequence that the filter becomes impervious. The surface layer must therefore be supported by intermediate layers. The upper intermediate layer must consist of 3 to 10 mm. material, followed by a 4-inch layer of 10 to 30 mm. material and a layer of the size of walnuts. Then comes the coarse material of the filter. If the above directions are strictly adhered to, on removing the surface layer from filters which have been in continuous operation for years, treating sewage at a high rate, it will be found that the layer of 3 to 10 mm. material scarcely shows any signs of clogging. Clogging of the surface layer may be avoided by occasionally turning over the top four or six inches with a shovel and allowing the filter to rest for a day or two. Previous to this the surface must be allowed to dry, and the surface film, consisting chiefly of paper-pulp, removed to a depth of not more than about $\frac{1}{5}$-inch with a smooth shovel. When first brought into operation, the surface of the upper layer of the filter first assumes a slimy character, afterwards becoming granular. I am of the opinion that this change is due to the formation of ferric hydrate.

The above described arrangement of the various layers was at first regarded as the fad of a theorist, and one or other of the intermediate layers have been omitted. The surface layer has then been washed into the coarse material, and the filter thus spoiled. It has had to be taken down, washed and sieved, or replaced by fresh material. In large works well known to me, this mistake has been made; and when the sewage would no longer pass through the filter, holes were made through the surface layer with stakes. This only made matters worse. In a German town of medium size, the authorities have adopted this system without considering it necessary to make any inquiries as to the principles of the process. Mistakes were accordingly made in the gradation of the layers, and the sewage ponded upon one side of the filter. At another place, in spite of the experience which has been gained to the contrary, sand was placed directly over coarse material. At present these works are still in operation, but they will not last very long.

The second great mistake which is made in constructing filters according to my system is that sufficient allowance is not made for rational aeration. It has been thought that the introduction of ventilating pipes was sufficient. My experience in this direction has already been mentioned. Under certain circumstances it is very difficult to effect side aeration, and I have accordingly had a series of experiments carried out on the ventilation of filters constructed on my system, in which, however, the sides of the filters were made perfectly tight. The results show that when the dust is carefully removed from the material, and the surface raked over sufficiently often, sufficient aeration may be effected from the top and bottom, if the depth of the filter is not too small. These aeration conditions are easily explained with the aid of the processes described on p. 175. Oxygen is absorbed by the filter, and a vacuum results, which is finally able to overcome the resistance of the surface layer. The action of this vacuum is greater in proportion as the quantity of air in the lower portions of the filter is greater. When the coarse material was about 6 feet deep, perfect saturation with oxygen and removal of carbon dioxide could be obtained, but this could not be obtained when the coarse material was only about 1½ feet deep, the conditions of experiment being in all other respects the same. When an aerating pipe was passed through the fine top layer into the coarse material, and the air withdrawn as from a chimney, satisfactory aeration could be easily maintained. For this reason I had recommended the introduction of such an aerating pipe in the works shown in fig. 139. The pipe was to be led up by the side of a kitchen chimney, but on account of the fall the works had to be constructed in another position, and the pipe was omitted. If sufficient aeration can be obtained through the sides of the filter, the layer of coarse material may be constructed of a comparatively small depth. I have constructed such filters with only about 8 inches of coarse material, and they have produced satisfactory results for long periods. This serves to illustrate the important fact that the system is applicable in cases where the available fall is rather less than 3 feet.

When I expressed the opinion above that the Hamburg system might be of interest at the present day, even with the present high development of the technical details of distribution, I had in mind, on the one hand, the little attention which is necessary, *i.e.* the filters may be left to themselves for a longer period than with any other method, and, on the other hand, the certain loss of head which is necessitated by all other methods of distribution. This loss of head is said to have reached a minimum in the Fiddian distributor. With the fixed forms of sprinkler, a pressure of 3 to 10 feet is necessary, varying with the construction of the sprinkler. Moreover, in view of the coarse nature of the material which is usually adopted in conjunction with such sprinklers, the filters can hardly be constructed less than 6 feet deep.

The only exception to this is afforded by Reid of Stafford, who has carried out experiments at Hanley with filters just over 3 feet deep. In England, Reid is regarded as the advocate of fine biological filters, and his experiments are everywhere attracting attention at the present time. The experiments were first commenced in 1904, several years after the commencement of our Hamburg experiments, and I have also formed the opinion that the works constructed on this system are not technically developed to the same extent as those constructed on the Hamburg system. In Reid's works, too, the distribution is not effected by the fine material, but by means of special distributing apparatus.

The Hamburg system has been patented, but I have decided to make the process public property, so that it may be adopted by anyone.

D. Degener's Lignite Method.

Sir E. Frankland considered it futile to search for a method by which the dissolved organic matters could be precipitated from sewage (p. 24). This problem was, however, solved in a most ingenious manner by Paul Degener, who, unfortunately, died young. Starting with the idea that dissolved organic substances can only be removed from liquids by absorptive action, and the assumption that it is the humus of the soil which effects this removal in the case of irrigation, he attempted to find substances containing a large proportion of humus. Peat and lignite appeared to be most suitable in this direction. Powdered lignite, however, when mixed with sewage, remained suspended in the liquid; but by the further addition of precipitants, such as iron salts, the required precipitation took place. The oxygen absorbed and the organic nitrogen in the effluent so produced had been considerably reduced, and the effluent was non-putrescible.

Degener's results must be regarded as epoch-making. They date from a period when general dissatisfaction prevailed with the hitherto known methods of chemical precipitation, and when it was recognised that irrigation and land filtration could only be adopted in rare instances. Degener's process appeared to have a great future before it, especially as hopes were raised of a profit from the extraction of the precipitated grease and manurial constituents of the sewage. Even those who had given up hopes of such a profit, on account of the failure of all previous processes, recognised a great advantage of this process over all other precipitation processes, in the fact that the sludge could at any rate be disposed of in furnaces.

Degener's process has, in the meantime, been adopted by various towns and institutions, *e.g.* at Potsdam, Spandau, Tegel, Soest, Reinickendorf, Oberschöneweide, at the Cable Works of Siemens & Halske, and at the Convalescent Homes at Uchtspringe and Sülzhayn. The number of works in existence is large enough to enable us to judge of the capabilities and cost of the process. When carefully managed, the process has always yielded satisfactory effluents, but no profits have been obtained. On the contrary, the process is the most costly of all methods of sewage purification which are in use at the present time. With the artificial biological processes which have become known since Degener's process was invented, it cannot compare either as regards reliability in working or as regards cost. Nevertheless, cases may occur here and there in which Degener's process may appear to be applicable, and on this account, as well as on account of the scientific value of the process, a short description follows. The Tegel works are generally regarded as the best example.

Tegel is sewered on the separate system, and has a population of 14,000, including that of the Borsig Works and a prison, connected with the sewers. The water consumption only amounts to 13·2 gallons per head per day; but, in spite of this, the average daily volume of sewage amounts to 330,000 to 774,000 gallons, of which 184,800 may be taken as domestic sewage and the remainder as trade refuse. The effluent is discharged into the Tegel Lake, from which, until recently, one of the large Berlin waterworks derived its supply. As may be seen from fig. 142, the sewage works are situated in a thickly populated district, and yet no complaints have ever been made of nuisances from smell. Sedimentation is effected in two towers constructed on the Rothe-Röckner principle. The sewage is pumped from a collecting well, 20 feet deep, into a mixing channel, 2 feet deep (K, fig. 143), where finely ground lignite is added (about 20 lbs. lignite per 1000 gallons sewage). After the lignite has become evenly distributed throughout the sewage, precipitants are added (at T), in the form of sulphates of iron or alumina (3 lbs. per 1000 gallons); the sewage next passes through a screen into circular channels surrounding each of the towers, whence it flows down the pipes (R, fig. 144) into the lower portion of the towers. Rising in each tower the current of the sewage is distributed by means of an apparatus constructed of iron bars. When the sewage inside the tower reaches the same level as that in the circular channel outside, the air is pumped out of the tower, and the sewage continues to rise with a velocity which should not exceed $\frac{1}{25}$-inch per second, so as to allow the sewage to remain in the tower from one and a half to two hours. Near the top of the tower there is another current distributor which conducts the sewage through a pipe passing down the outside of the tower into the effluent channel, which is about six inches lower than the water-level in the circular channel surrounding the tower. After being set in action, therefore, the tower

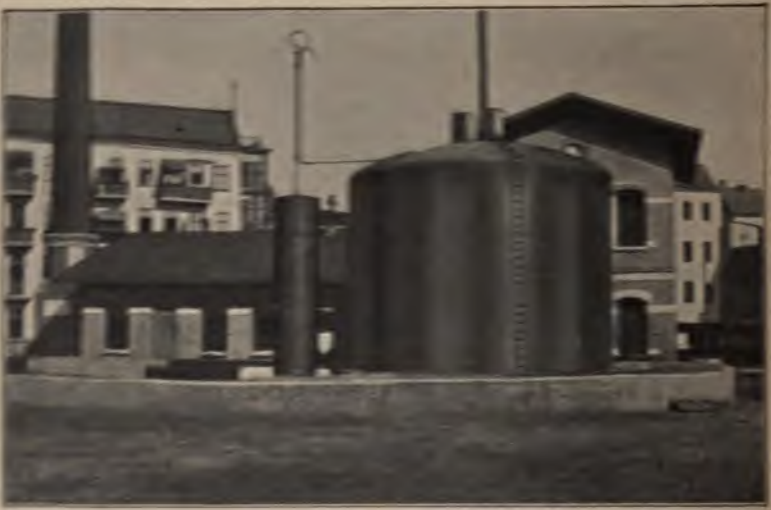


FIG. 142.—Lignite Method, Tegel Works.

works just described require eight persons, besides the manager, six being employed in the day-time; one fireman, one workman for the lignite-grinding and stirring plant, three workmen for the sludge presses and cartage of the sludge, and one workman for sludge drying and cartage of fuel.

The cost of erecting the Tegel works was just over £10,000; the annual working cost is £1550 (1903). Including interest and sinking fund (113·6 shillings per million gallons of sewage, or one shilling per head of population per annum), the total working cost amounts to 372·7 shillings per million gallons, or 3·22 shillings per head of population per annum. In the Tegel works, however, it should be borne in mind that a considerable proportion of the cost is due to trade refuse. After making allowance for this, Schury and Bujard calculate the net working cost at 1·81 shillings per head per annum.

At Potsdam the sewage of a population of 60,000 is purified by the lignite method. The sludge is burnt in the neighbouring municipal electricity works. After allowing for the income derived from this source, Wimmer calculates the cost of the process at Potsdam to be 1·20 shillings per head per annum.

At Spandau the sewage of about 63,000 persons is treated by Degener's process. The dried sludge produced daily amounts to three and a half tons; it is pressed into briquettes, and sold for about seven shillings a ton, a small portion being also sold for manurial purposes. Wimmer calculates the total cost of the process to be 1·39 shillings per head per annum, or 312·3 shillings per million gallons of sewage treated.

At Oberschöneweide the cost of purification, including interest and sinking fund, is said to be 250 shillings per million gallons of sewage.

According to Proskauer, the degree of purification produced when the works are carefully managed is satisfactory both from the chemical and physical standpoint. The organic nitrogen and the oxygen absorbed are reduced by 60 to 80 per cent., and the effluent is non-putrescible. According to the reports of the supervising authorities, the purification effected at Tegel was very variable, *e.g.* in 1899 the reduction in the organic nitrogen varied from 14 to 96 per cent., and in 1900 from 33 to 95 per cent. The variations are said to have been mainly due to temporary overworking of the apparatus.

In times of epidemic, Proskauer is of the opinion that the purified effluent may be sufficiently disinfected within a few minutes by the addition of 2·5 lbs. of lime or 0·15 lb. of chloride of lime per million gallons of sewage.

According to the experiments of Reichle and Dost, the calorific value of the sludge obtained from Degener's process is not entirely due to the lignite added, 11 to 30 per cent. of the total calorific value being due to the matters precipitated from the sewage. The calorific value of the gas which has up to the present been obtained from the sludge is only small, but the above-mentioned authors believe that a not inconsiderable reduction of the cost of working may accrue from a gasification process. They recommend experiments in open settling tanks in which less expensive precipitants might be used ; and they are of the opinion that, if the technical process of gasification can be perfected, the lignite method of sewage purification might be combined with a municipal power station, because of the small area necessary and because of the possibility of thus disposing of the sludge.

CHAPTER IX.

THE DISINFECTION OF SEWAGE.

Infectiousness.

Contamination of Rivers.—Domestic or town sewage contains very large numbers of micro-organisms; seldom less than a million per c.c., and often as many as ten millions or more. The majority of these bacteria are quite harmless. In cases of infectious intestinal diseases, however, such as cholera, typhoid, and dysentery, the germs of these diseases find their way into the sewage. The germs of diphtheria, tuberculosis, infantile summer diarrhœa, and of many other diseases, may also be present. Besides the above, sewage contains definite species of bacteria, which have been shown to be very virulent when inoculated into animals. Among these should be mentioned *Bacillus enteritidis sporogenes*, the spores of which, according to Houston, are generally present in sewage to the extent of 1000 or more per c.c. Houston also found not less than 1000 *Streptococci* per c.c., but the question as to how many of these *Streptococci* are pathogenic remains undecided.

If guinea-pigs are inoculated with only small doses of sewage, they become ill almost without exception, and often die. The drinking of sewage must accordingly be regarded not only as unappetising, but also as likely to be hurtful to health, and, in cases of epidemic intestinal diseases, as directly dangerous. If sewage is discharged into water-courses, danger may result under certain circumstances. At the present day it is generally recognised that the water of rivers which have passed through populated districts is not in its raw state fit for drinking and other domestic purposes, and most towns have abandoned the use of untreated river water. They have either made themselves independent of river water by using well-water, or they draw their supplies from streams which are specially protected against pollution. Where freedom from pollution is not possible, the river water is subjected to a filtration process, and at the present day the question of a further treatment, *e.g.* ozonisation of the filtered water, is being very much discussed.

Under the above conditions we are chiefly concerned with those cases *in which* individual persons occasionally drink river water or otherwise come into contact with it. The main factor in this direction is formed by the floating population, which amounts to some thousands on the German rivers and streams. Care is indeed taken that boatmen can supply themselves as far as possible with drinking water at all landing places. The danger of infection which is connected with the consumption of unboiled river water is also widely made known. Hence, if the boatman drinks water drawn directly from the river, he does so at his own risk, and must be responsible for the consequences. The boatmen usually discharge all their waste products into the rivers; and if they are suffering from intestinal disease, they infect the portion of the stream over which they travel and thus endanger the health of others. So long as it is safe to assume that pathogenic germs can only survive for a few days in our open water-courses, and that they cannot multiply or only to an inappreciable extent therein, it is not necessary to fear that the above conditions will give rise to serious epidemics.

With regard to the questions as to how long pathogenic germs, such as the bacilli of cholera and typhoid, can survive in river water, and as to whether and under what conditions they can multiply therein, the evidence in my opinion is not yet complete. Personally, I cannot share the generally prevalent opinion that the bacilli of typhoid, cholera, etc., die rapidly in our water-courses. On the other hand, the experience of last century has shown us that by simple precautions, such as sand filtration, a seriously infected river water may be practically completely deprived of its infectious character, so long as the filtration process is properly conducted. This fact forms the commencement in considering the question as to how far precautionary measures must be adopted in order to deprive sewage of its infectious character before being discharged into a water-course.

The standpoint to be adopted will be that in populated districts, even if the sewage is not systematically discharged into the river, the river water is a possible danger to health and unsuitable for drinking and other purposes, but that practical measures can be adopted to convert it into water which is unobjectionable from a sanitary point of view. In the case of rivers which serve as sources of water supply, in spite of these practical measures which may be adopted, attempts should be made to restrict the infection to a minimum. In the case of rivers which are not used as sources of water supply, bathing places will have to receive consideration, as well as the river population, and the fact that the water of such rivers may come into contact with food destined for human consumption, as in the washing of milk pails, the rinsing of vegetables, etc. The infection of fishes is not of such great importance, as fishes are usually boiled before being consumed. The discharge of sewage into the sea may give rise to the infection of shellfish, which is mainly consumed unboiled. Since the thorough investigations which have been made in England, it can no longer be doubted that oysters can be and often have been the cause of outbreaks of cholera and typhoid. This view is also confirmed by careful experiments which have been made in America.

Precautions against River Infection.—From what has been said it will be clear that sewage, almost without exception, must be regarded with suspicion, and that under certain circumstances it must be regarded as infectious. In all cases where it is a question of discharging sewage into a river, the possibility of spreading infectious diseases must be considered. This possibility varies with the conditions of the river, the density of the population, and the amount of traffic on the river, and must be dealt with in each individual case. In certain circumstances it will be necessary to adopt measures for the separation or destruction of the infectious germs either permanently or temporarily. As in all hygienic questions, so in this it will be necessary to have regard to the various opposing interests and to the question of cost. For this reason only those measures which are not excluded for the above reasons will be dealt with here.

"Disinfection" Defined.—In the first place, we have to consider how far the methods of sewage purification which have been enumerated in preceding chapters are suitable for depriving sewage of its infectious character. This may be accomplished either by separating the infectious germs from the sewage or by their destruction. The latter we call disinfection. The question of separation of the micro-organisms will be dealt with later; the more complicated problem of disinfection will be first considered.

Indicators of Contamination.—Disinfection in this connection must not be considered as equivalent to sterilisation, for sterilisation implies the complete destruction of all the germs present in the sewage. If sterilisation could be carried out as easily and as cheaply as disinfection, it would certainly be preferable, on account of the greater ease with which it may be controlled. Sterilisation is, however, much more difficult and more expensive than disinfection; and since the majority of sewage bacteria may be regarded as harmless, disinfection, or the destruction of the pathogenic germs, is generally considered sufficient. Even in the excreta of patients suffering from typhoid and dysentery, the pathogenic germs of these diseases are found along with many other bacteria, and consequently, even in strongly infected sewage, their number is not very large in comparison with the number of other sewage bacteria. With the means at our disposal it is very difficult to prove the presence of pathogenic germs among all the other bacteria, and the supervision of a disinfection process cannot be carried out by testing whether pathogenic germs can be developed in the treated sewage. Other indirect methods must be employed. In 1892 I drew attention to the fact that the presence of *Bacillus coli* affords a good guide to the presence of fæcal matter in water. These bacilli are found in large quantities in the intestinal excreta of nearly all animals; and since sewage is chiefly dangerous on account of intestinal diseases, *i.e.* because pathogenic germs find their way into the sewage along with the contents of the intestines, the presence or absence of *Bacillus coli* allows fairly safe conclusions to be drawn as to the fear of infection. A year later, Theobald Smith also recommended the use of *Bacillus coli* as an indicator, as a result of experiments which he carried out in 1891, in the same year as my own experiments were carried out. Since then *Bacillus coli* has come to be regarded as a useful indicator in this connection. In examinations as to the infection of well or river water it is now customary to test for *Bacillus coli.* In the disinfection of sewage, the *Bacillus coli* appears to me to be an equally useful indicator. Not only is its presence certain in cases of cholera, typhoid, dysentery, and other intestinal diseases, but as regards its persistence under adverse conditions it is very similar to the typhoid bacillus. This is especially the case as regards increase of temperature and the action of chemicals. As a further advantage, the fact must be regarded that *Bacillus coli* is rather more persistent than the typhoid bacillus, and that it is always present in sewage in larger numbers than the specific pathogenic organisms. Hence, measures which lead to the separation or destruction of *Bacillus coli* may be safely assumed to dispose of the typhoid bacillus and the equally sensitive germs of cholera, dysentery, etc. *Bacillus coli* may be tested for in sewage without difficulty. It forms gas in media containing sugar, and may be recognised on plate cultures in which Drigalski's medium, Endo's agar medium, Rotberger's neutral red agar, and other special media are employed. In the absence of the possibility of directly testing for the presence of living pathogenic germs, the author has employed *Bacillus coli* as an indicator. In the meantime this practice has also become general, especially in testing the efficiency of the disinfecting plant at sewage works, where it must be regarded as inadmissible to infect large volumes of sewage, which have to enter the streams, with pathogenic germs even for purposes of experiment. In our disinfection experiments, shortly to be described, we have employed the *Bacillus coli* as our general indicator.

Also in experiments on the removal of pathogenic germs from sewage, the *Bacillus coli* has hitherto formed the only useful indicator. Whilst it is not possible to detect the specific pathogenic germs with which we are concerned in sewage, and other virulent bacteria which are usually found in sewage, such as *Streptococci* and *Bacillus enteritidis*, only occur to the extent of a few hundreds or thousands per c.c., *Bacillus coli* is generally present to the extent of not less than 100,000 per c.c. If, therefore, the effluent from a sewage purification works contains none or only a few coli bacilli, it may be assumed that specific pathogenic germs are absent, in view of the fact that *Bacillus coli* is very similar to the typhoid bacillus and much more resistant to adverse conditions than the specific pathogenic organisms.

Removal of Pathogenic Bacteria.—It must not be assumed that the infectious intestinal bacteria are free to move about in sewage. Even in diarrhœa stools a large percentage are enclosed in gelatinous masses and in suspended matter. Any process which removes the suspended matter from sewage will therefore remove a large percentage of the pathogenic bacteria at the same time. Our comparative experiments on the action of large sedimentation tanks in removing bacteria from river water, which have now been carried on for some years at Hamburg, have shown that, when the suspended matters were removed to the extent of 30 per cent., the bacteria were also removed to about the same extent. In sewage a large portion of the suspended matter is of an organic nature, and composed largely of micro-organisms, and hence the action of sedimentation in removing bacteria will be greater than in the case of river water. All the above-described processes of sewage treatment which aim at the removal of suspended matters only, such as detritus tanks, screens, sedimentation tanks, etc., will succeed at the same time in considerably reducing the number of infectious germs in sewage. A complete removal of all bacteria cannot, however, be expected of such processes. For a long time it was believed that the action of chemical precipitants was so far inimical to infectious germs as to completely destroy them; but this view has been proved to be erroneous, as will be seen from the results of experiments described later. A greater reduction in the number of pathogenic germs may, however, be expected from processes of chemical precipitation than from simple screening or sedimentation. The deposit obtained in either case must be regarded with suspicion.

With regard to septic treatment, views have been published to the effect that pathogenic germs are quickly destroyed in septic tanks. This is by no means the case. It has been shown that the number of *Bacillus coli* can be reduced by 40 or 50 per cent. in passing through septic tanks; but such a reduction, or even a larger reduction, may be explained by the sedimentation which takes place, without ascribing any inimical action whatever to the septic process. I have had experiments carried out with a cholera-like vibrio, which, as regards resistance, is quite comparable to the extremely sensitive cholera vibrio. These micro-organisms are specially suitable for such experiments, because they phosphoresce, and hence the colonies may be easily recognised on plate cultures. They can, however, only be used as an indicator in cases where it is a question of destroying cholera vibrios or other equally sensitive micro-organisms; they are not so resistant as typhoid bacilli. Our experiments showed that these micro-organisms remained active for thirty-three days in a septic tank and only ceased to be recognisable after this period. This example serves to show that septic treatment does not afford a safe means of disposing of pathogenic organisms.

Great hopes have been raised as to the removal of the infectious character of sewage by biological processes of treatment. One of the *main* advantages of irrigation, as we have seen in the chapter dealing with this subject, has been the assumed retention of pathogenic germs. Direct experiments on this point have not been made. It is well known that the number of bacteria in the effluents from properly working irrigation farms is considerably less than in the crude sewage. At the Brunswick farm, for example, the number is reduced from 1,721,000 to 5591 per c.c., *i.e.* by 99·7 per cent.; at the Freiburg farm from 840,400 to 67 per c.c., *i.e.* by practically 100 per cent. On the other hand, in other carefully constructed and well-managed irrigation farms, with exceptionally suitable soil, I have regularly found *Bacillus coli* in the effluents. In the effluents from three different farms I have found coli or coli-like bacilli in 0·0001 to 1·0 c.c.

The officers of the present English Royal Commission have tested the best English irrigation farms and come to a similar conclusion. They state that land treatment does not alter the bacterial character of sewage; that all typical sewage bacteria, *Bacillus enteritidis sporogenes*, *Streptococci*, and also *Bacillus coli*, are to be found in the effluents, whilst they are absent in soil which has not received sewage. They state that the number of bacteria is diminished, but that the character remains unaltered. The relative amounts of the various bacteria also apparently remain uninfluenced. Such experiments do not necessarily prove that cholera vibrios and the bacilli of typhoid are not retained by the soil; but from the results of our own careful experiments with intermittent filters I have no longer any doubt that these pathogenic organisms do pass through irrigation areas along with the effluent.

As regards the question under consideration, intermittent filters are similar to irrigation farms. When they are worked under favourable conditions, as in Massachusetts, it is possible to reduce the number of bacteria very considerably, and to obtain effluents which yield a negative coli test with 100 c.c. Such results can only be produced, however, under very favourable circumstances, for even cholera-like vibrios can pass through intermittent filters. We charged such filters with sewage containing a million vibrios per c.c., and found in the effluent 10,000 per c.c.

We have carried out numerous investigations with artificial biological filters, and always found that they do not deprive sewage of its infectious character. Opinions which have been expressed to the effect that they considerably diminish or even quite destroy the infectious nature of sewage are undoubtedly erroneous. The results which we obtained were only to be expected, but the tests have been made in order to furnish positive evidence against contrary opinions. Even the very sensitive vibrio described above passes through every kind of artificial biological filter in a very short time. The effluents from such filters contain more living bacteria than the effluents from irrigation farms or land filtration areas, and hence the number of pathogenic germs which can pass through such filters will be large. Are the results of these experiments to be interpreted as showing that the action of biological filters in removing bacteria is negligible? Discussions with various experts have led me to believe that there is a tendency at the present time to answer this question in the affirmative. Personally I cannot share this view.

In cases of infection the influence of quantity or mass is not so great as in chemical reactions, for this influence is largely affected by the multiplication of the micro-organisms. On the other hand, I consider it to be, however, an epidemiologically ascertained fact that in cases of infection the number of pathogenic bacteria which gain access to the human body is of considerable importance. Of course, a weakened subject reacts to a very small number of pathogenic germs, but such exceptions are to be found to all rules. Generally speaking, the reduction in the number of pathogenic germs, such as is effected by good irrigation or land filtration, must be regarded as a great advantage. This is especially so from the fact that such works retain the suspended matter, which serves as a hiding-place, a means of subsistence, and a vehicle for the bacteria. The retention of the suspended matter also makes more difficult the fight for existence on the part of the comparatively few organisms which do find their way into the stream. A similar action must be attributed to those processes of sewage treatment in which a less thorough removal of the suspended matters is effected, except that, in so far as only the suspended matters are attempted to be removed, the separation of bacteria is not so complete as in the case of biological processes.

The question as to what becomes of the pathogenic germs which are separated from sewage and which remain on and in the soil will not be further considered here. It has already been mentioned that, in spite of the facts that irrigation has been used for over a hundred years, and that very thorough investigations have been made on the point, no case is known where epidemics have been traced to irrigation farms.

Where the conditions are such as to necessitate a thorough purification of sewage from a chemical standpoint, the requirements from a bacteriological standpoint will be similar, and consequently regard must be paid to the capabilities of the process which it is intended to adopt as regards the separation of pathogenic germs. A complete separation or destruction of pathogenic germs is not, however, possible with any one of the methods of purification which have been successfully adopted on a practical scale. Hence, in cases where pathogenic germs must necessarily be removed from sewage, special measures must be adopted. No process of filtration is known which will effect the object in question. In filtration experiments carried out for the English Royal Commission the bacilli of typhoid and cholera have not been detected in the effluents from the filters; but if such a filtration process were to be adopted in connection with a sewage purification works, filter beds would be necessary at least equal in area to those used for the filtration of drinking water, and even then equally good results with those obtained in the above experiments could not be relied upon. Generally speaking, I do not regard the removal of pathogenic germs by means of filtration as practicable. Methods depending upon heat or chemicals can, therefore, alone be considered.

Typhoid bacilli and all the other pathogenic bacteria which we have considered, as well as the *Bacillus coli communis*, which we have used as an indicator, are killed in a few minutes if exposed to a temperature of 60° to 70° C. Spore-forming bacteria, such as the bacilli of anthrax and tetanus, resist the action of even higher temperatures when in the form of spores; but, except in special cases, a discussion of which would occupy too much space here, these bacilli have little importance in sewage treatment. With town sewage thermal disinfection can scarcely assume practical importance, on account of the danger to which the constructional parts of the works would be thereby subjected. The method may, however, be used on a smaller scale, under circumstances which will be dealt with later. Generally, however, the disinfection of sewage will be best attained by chemical methods.

Disinfection.

By Chemical Means.—Until 1893 the disinfection of sewage was regarded as a comparatively simple and inexpensive problem. It was thought that the addition of lime, until the sewage reacted slightly alkaline, was sufficient to kill any typhoid or cholera bacilli which might be present. This view has not, however, been confirmed, and the published results of the Hamburg investigations appear to have received due consideration in Germany. The same cannot be said of England, where at the present time there are authors who hold the view that sewage may be disinfected by the addition of comparatively small amounts of various chemicals, and consequently at a small cost. If the matter had really been so simple it would certainly not have been necessary to spend as many years as I have done in experimenting on this subject. About ten years ago it was shown by Dr Zirn and myself, by experiments with over 400 samples of sewage, that it is not always possible to kill the sensitive bacilli of typhoid and cholera within 6 to 12 hours by the addition of one part of calcium hydrate, $Ca(OH)_2$, to 500 parts of sewage, even when the sewage is comparatively dilute. Lime is regarded as a relatively strong disinfectant, and hence the above results form a useful guide in judging of the value of various recommendations which have been made for the chemical disinfection of sewage. In the following table are given the results of comparative experiments in a form which expresses the cost of obtaining a definite disinfecting action, the cost of obtaining such action by means of chloride of lime being taken as unity:—

COST OF DISINFECTION.

Disinfectant.	Relative Cost compared with Chloride of Lime.
Chloride of lime	1
Lime	2
Cuprous chloride	4
Potassium permanganate	6
Chloros	6
Eau de Javelle (sodium hypochlorite)	8
Commercial sulphuric acid	10
Crude carbolic acid	20
Mercuric chloride	25
Commercial ferrous sulphate	40
Commercial copper sulphate	150
Lysol	500
Formalin	500

The above results were obtained in experiments which were subject to the objection that the sewage used was variable in composition. Reliable and definite results can only be obtained by taking the average of repeated experiments. My own experiments are as yet scarcely numerous enough for this purpose, and hence some of the above figures may be subject to correction. One fact may, however, be regarded as certain, viz., that none of the disinfectants suggested for the disinfection of sewage can approach chloride of lime as regards lowness of cost. It may be mentioned that, besides the disinfectants enumerated in the above list, others were employed which have been recommended for this purpose. They included chinosol, spiritus saponatus, boric acid, borax, lead acetate, salicylic acid, hydrogen peroxide, alsol, cupric chloride, etc. None of these produced sufficiently satisfactory results to justify their inclusion in the above table.

Chloride of lime in a concentration of 1 in 15,000, or 1 in 10,000, is more efficacious than lime in a concentration of 1 in 500. Although chloride of lime is considerably more expensive than lime, disinfection with its aid is cheaper than with lime. Moreover, lime, when added to sewage in the quantities necessary to disinfect, produces a considerable amount of sludge, whilst chloride of lime under similar conditions causes practically no precipitation in the sewage.

The above experiments were carried out with sewage from which the suspended matters had been previously removed. The conclusions are, therefore, not directly applicable to the practice of sewage disinfection, especially as the pathogenic germs are largely to be considered as being enclosed in organic particles in the sewage, and not freely distributed throughout the liquid. A disinfectant for sewage must therefore be judged on its power of penetration. On this point experiments have been made by Schumacher, and have resulted in favour of chloride of lime as compared with lime. Lumps of agar, 1 mm. in diameter, were not penetrated by lime in a concentration of 1 in 500, nor by chloride of lime of the same strength. Coli bacilli contained within the lumps of agar remained undestroyed. Smaller pieces of agar, 0·75 mm. in diameter, were not penetrated by lime of the above concentration, but were penetrated by chloride of lime, 1 in 1000, four times out of five experiments, and by chloride of lime, 1 in 2000, three times out of five experiments. Lumps of agar, 0·5 mm. in diameter, were penetrated twice out of five experiments by lime in a concentration of 1 in 500, and four times out of five experiments by chloride of lime of a strength of 1 in 2000.

In our further experiments we have used *Bacillus coli* as an indicator to test whether non-sporing pathogenic organisms were destroyed, and the above-mentioned phosphorescent vibrio to test whether the less resistant pathogenic germs were destroyed. It had previously been shown that this vibrio possesses the same resistant powers against the action of chloride of lime and lime as the vibrio of cholera. We also proved that typhoid bacilli are rather less resistant than coli with regard to both these disinfectants. *Bacillus coli* is also more resistant than *B. pyocyaneus*, the diphtheria bacillus, staphylococci, and *Proteus*. These facts, which were ascertained in the laboratory, have been confirmed later on the large scale; for, in sewage in which the coli bacilli had been killed, we very rarely found other bacteria than sporing forms. If *Bacillus coli* is chosen as our indicator, the testing of the effect produced by disinfectants is not as simple as could be desired, for *Bacillus coli* does not possess any specific properties by which it can be immediately recognised among other bacteria. The introduction of Drigalski's nutrient medium has considerably simplified its isolation and recognition, but the colonies which appear as coli on the Drigalski plates must be subjected to further tests which are somewhat tedious. For a hygienic institution where such tests are being continually carried out, such a control or supervision of the disinfection process lies within the limits of possibility, but for individual institutions it is scarcely practicable. A simpler method of control is, therefore, very desirable. In the first place, we may regard it as certain that the character of the sewage will influence the disinfection by means of chloride of lime to a considerable extent. Our experiments have confirmed this view, and it may be stated that generally the more concentrated the sewage, *i.e.* the greater its oxygen absorbed figure, the more chloride of lime is necessary for its disinfection. Schumacher showed, however, that this guide is not quite reliable, and that under certain conditions a sewage having an oxygen absorbed figure of 86·0 parts per 100,000 required very little more chloride of lime than a sewage having an oxygen absorbed figure of 35·0. Neither does the estimation of the suspended matters in the sewage afford a better guide, for their nature and, consequently, their power of absorbing chlorine is too varied. The chlorine is destroyed by sulphuretted hydrogen, as also by the disinfectants which are to be found, often in very large quantities, in the sewage of hospitals. This was shown to be the case by Schumacher, and Schwarz has further investigated the problem. The latter has shown that carbolic acid most of all, but that also cresol and lysol considerably diminish the disinfecting power of chloride of lime. Mercuric chloride and lysoform do not interfere with its action. Besides these two disinfectants and chloride of lime, *Liquor cresoli sapon* is one of the most important which can be used in cases where an effectual disinfection is required.

An estimate of the amount of chloride of lime necessary for disinfection could not, therefore, be made by determining the concentration of the sewage, and it was thought that perhaps from the excess of free chlorine remaining in the sewage after disinfection information could be obtained on this point. R. Schulz has carried out some experiments for me in this direction, and his preliminary experiments showed the applicability of the method. Conclusions can, however, only be drawn from the results of very numerous observations, and these have been conducted by Dr A. Schumacher with such patience as can only be appreciated by those who have attempted to master the complicated difficulties which are met with in such experiments. The results of his numerous series of experiments are to be found in the publication cited; they have convinced us, however, that the excess of free chlorine remaining after the disinfection of sewage gives definite information as to the result of the disinfection. The quantity of chlorine thus remaining is, of course, dependent upon the quantity of chloride of lime added in the first instance, and also upon the length of time during which the action is continued. The latter factor is specially important; for the longer the action of the chloride of lime is allowed to continue the more certain is the result, but the quantity of free chlorine remaining is then less. The period of action must, therefore, be accurately known. Schumacher finds that when chloride of lime in a strength of 1 in 2000 is employed and allowed to act for two hours, the residual chlorine must amount to 4·9 parts per 100,000, if the disinfection is to be efficient. Similarly, using a strength of 1 in 5000 for two hours, the residual chlorine must be 2·1 parts per 100,000. Schumacher finds that under these conditions, if 100 samples of the effluent, each 1 litre, are examined, *Bacillus coli* will be absent in sixty-two cases. From this it will be seen that with smaller volumes of the effluent, such as are generally used in tests, *Bacillus coli* will be absent. This important point requires further consideration.

It used to be customary, in testing the effect of sewage disinfection, to examine 1 c.c., or even a fraction of 1 c.c. After the adoption of the concentration method in conjunction with the use of peptone this quantity was increased. At Hamburg we used 50 or 100 c.c., and later as much as a litre. In the examination of river water for typhoid bacillus *it is now* usual to employ ten litres, and if the process is continued much further it will be necessary to convert a thousand litres of the water into cultures and incubate this enormous volume. For scientific investigations, such as are carried on in our laboratories, the value of using such enormous volumes is of course undeniable, and it has to be done, but it does not appear to me to be necessary to introduce these methods into technical routine tests. The examination of a litre of sewage is equivalent to the examination of 1000 samples each 1 c.c.; and if coli bacilli are absent in this volume it may be safely concluded that none or only very few remain in the whole volume of sewage which has been disinfected. Is it worth while to carry out tests even to this degree of fineness? We have seen that *Bacillus coli* is always present in the effluents from irrigation farms, and in these cases the examination of 1 c.c., and often of 0·01 or 0·001 c.c., is sufficient for the purpose. Even in the effluents from very carefully operated waterworks filters, it is possible to find coli bacilli when these are present to any appreciable extent in the unfiltered water. Bearing these facts in mind, I do not see any necessity for carrying the disinfection of sewage to such an extent that not a single coli bacillus escapes from the disinfecting plant. I consider it quite sufficient to conduct the test with 1 c.c. This conclusion is based on the fact that for every single pathogenic organism which may be present in sewage, hundreds or even thousands of coli bacilli are present; and if we cannot find a single coli bacillus in 1 c.c. we cannot expect to find a single specific pathogenic organism even by the examination of several thousand litres of the liquid. The experiments of Schumacher were very necessary to determine the practical limits to which disinfection can be carried out. By the addition of 5 lbs. of chloride of lime to 1000 gallons of sewage, *i.e.* 1 in 2000, after two hours' action, Schumacher found coli bacilli in 12 out of 100 samples, each of one litre. With chloride of lime 1 in 5000 he found coli bacillus in 38 out of 100 samples, a litre of effluent being converted into culture each time. One naturally asks what results would have been obtained if, instead of a litre, 1 c.c. had been examined. In continuation of Schumacher's experiments, Schwarz has shown that cholera-like vibrios were killed by chloride of lime, 1 in 5000, even when a litre of effluent was examined. The same results were obtained by the use of chloride of lime of a strength of 1 in 10,000 and 1 in 20,000. On using a strength of 1 in 30,000, and examining a whole litre, vibrios were found in 2 out of 10 samples; on examining 50 c.c., once out of 10 samples; and on examining 1 c.c. vibrios were not found once in 10 samples. On testing for *Bacillus coli*, after using chloride of lime, 1 in 2000, for four hours, coli bacilli were absent in 82·5 per cent. of the samples examined, when a whole litre was submitted to the test; this result agrees with those obtained by Schumacher. When 50 c.c. were examined each time, coli bacilli were absent in about 95 per cent. of the samples; and when only 1 c.c. was examined, coli bacilli were absent in all samples. The same results were obtained with certain sewages by using chloride of lime in strengths of 1 in 10,000 and 1 in 20,000, so long as only 1 c.c. of the sample was submitted to the test.

The following table shows the number of developable organisms remaining in sewage, originally containing about one and a third million bacteria per c.c., after treatment with chloride of lime for four hours:—

REDUCTION OF NUMBER OF BACTERIA, WITH VARYING ADDITIONS OF CHLORIDE OF LIME.

Chloride of Lime added.	Average Number of Bacteria per c.c.	
	Crude Sewage.	Tank Effluent.
1 : 2,000	1,350,000	15
1 : 5,000	1,350,000	23
1 : 10,000	1,350,000	36
1 : 20,000	1,350,000	72
1 : 30,000	1,350,000	3,620
1 : 40,000	1,350,000	59,000

The table shows that even with chloride of lime of a strength 1 in 20,000 the number of bacteria is reduced to less than 100 per c.c. On examining the results published by Schwarz, one obtains the impression that for all practical purposes it is sufficient to add chloride of lime, 1 in 5000, to ordinary sewage, and to allow its action to continue for two hours, in order to destroy the germs of typhoid, dysentery, cholera, and pathogenic germs of similar sensitiveness.

At Hamburg, several of the larger hospitals and similar institutions disinfect their sewage with chloride of lime in specially constructed cesspools. Schumacher thus had an opportunity of testing the results of his experiments on a practical scale, but it appears to me that the results which he obtained in this manner are not directly applicable to the conditions existing in cases where it is a question of disinfecting the total sewage of a town. In such cases specially constructed plant does not exist. The literature on the subject would lead one to believe that it is only necessary to add the disinfectant at any point along the line of the sewers in order to effect the complete destruction of the pathogenic germs within a few minutes. The above-described Hamburg experiments ought to be sufficient to remove any false impressions on this point. The number of towns is continually increasing in which it is necessary to pass all the sewage through settling tanks, and these are now being operated almost exclusively on the continuous principle, *i.e.* the sewage enters continuously at one end and leaves the tank in a continuous stream at the other end. With the object of ascertaining whether perfect disinfection could be obtained when working in this manner, I had one of the tanks at the Hamburg experimental works so arranged that it was filled by the *incoming* sewage on an average in four hours. With a continuous flow, then, it must be assumed that the sewage remained for four hours in the tank, provided that the distribution and flow were regular. With this tank Schwarz has carried out experiments in which cholera-like vibrios were mixed with the inflowing sewage. It was shown that these vibrios were very soon found in every portion of the tank, and that when they were no longer added to the incoming sewage they were still to be found in the tank for several days. As a second indicator, *Bacillus coli* was employed, as it was always present in the sewage in considerable quantities. The experiments of Schwarz, which were carried out in a very thorough manner, showed that the vibrios were destroyed by a very small addition of chloride of lime; so that on examining a litre of the tank effluent, after chloride of lime, 1 in 20,000, had acted in the tank for four hours, vibrios were never found to be present. *Bacillus coli*, which, as already mentioned, served as an indicator for disinfection against typhoid, was found in three out of seventeen litre samples, after the addition of chloride of lime, 1 in 2000. When 1 c.c. samples were examined, *Bacillus coli* could not be detected even after the addition of chloride of lime, 1 in 10,000 and 1 in 20,000. Only on one occasion were coli bacilli found after chloride of lime, 1 in 5000, had been used.

In these experiments the disinfected sewage was conducted to a biological filter without previously neutralising the residual free chlorine. This procedure might be expected to cause a diminution in the action of the filter. When carbolic acid, mercuric chloride, and similar disinfectants are employed, this is indeed the case; absorption soon ceases, and it is not long before the effluent leaves the filter in a putrescible condition. With hypochlorite, the active constituent of chloride of lime, however, reduction takes place in the uppermost layers of the filter, and its further action is prevented, as I have been able to show in conjunction with Dr Korn. In the lower layers of the filter even the sensitive nitrifying organisms remain undisturbed, and the processes of purification and oxidation can continue unhindered.

It was desirable to confirm the results obtained with small filters on a somewhat larger scale, and hence the disinfected sewage was discharged on to a filter of about sixty-five square yards' surface area. Schwarz showed, in the first place, that when the disinfectant was not used the vibrios were discharged in large quantities in the filter effluent. After the addition of chloride of lime, the action of the filter continued as before. Vibrios were absent in the sewage which reached the filter, and they soon disappeared from the filter effluent. *Bacillus coli* remained present in the filter effluent rather longer than vibrio, but also disappeared in a short time.

Having regard to the established fact that the action of chloride of lime does not penetrate deeply into the solid matters, the experiments of Schwarz were carried out with sewage which had passed through a millimetre sieve. We consider it necessary that all suspended matter larger than 1 mm. in size should be removed from sewage before it can be

16

satisfactorily disinfected. In the later experiments this removal was effected in a settling tank which served at the same time as a disinfecting tank. Schwarz convinced himself that the sediment remaining in the tank was not sufficiently disinfected to be admitted to the sewers along with the ordinary sewage. Hence a thorough sewage disinfection must also have regard to the separate treatment of this sediment. In the first place, the suspended matter may be separated by means of screens or similar apparatus, by sedimentation, or by chemical precipitation. With screens a small quantity of material is obtained which contains comparatively little moisture, and which is therefore easy to handle; with settling tanks or chemical precipitation a much larger quantity of a wet sludge is obtained, which is very difficult to drain. Neither process could be adopted within the grounds of a hospital without causing a nuisance, and the operation would require considerable expenditure. Of the various known forms of apparatus, the only suitable one appears to me to be Riensch's circular sieve, which is in operation at Dresden. From about 25,000 gallons of sewage this sieve would not separate more than about four cubic feet of solid matter in such a condition that it could be easily disinfected by heating to 70° C., by addition of disinfectants, by burning under boilers, or by some similar method.

Besides such an apparatus, the septic process also appeared to me to be applicable for purposes of disinfection. In this process, as we have seen, the organic solids, in which the pathogenic germs are enveloped, become gradually broken up or dissolved. The effluents from septic tanks contain only small amounts of suspended matter, and this is no longer present in the flocculent form, but is of a more or less broken granular character. The sulphuretted hydrogen in these effluents might be a disturbing factor. In order to investigate the applicability of the septic process, sewage was first passed through a septic tank at such a rate as to remain for nine hours in the tank. Chloride of lime, 1 in 10,000, was then added to the effluent from the septic tank and allowed to act for three and a half hours. *Bacillus coli* was absent in 100 c.c. of the effluent in 100 per cent. of the samples examined. Thus the introduction of the septic tank gave better results with one-fifth of the amount of chloride of lime which had been necessary when treating the crude sewage. When the tank was allowed to stand for a day or two, the results obtained on continuing the experiments were not so good, and determinations of the amount of sulphuretted hydrogen led to the conclusion that the increasing quantities of this gas had caused the poorer results. The effluents from septic tanks therefore which contain much sulphuretted hydrogen require larger quantities of chloride of lime, but not by any means as much as is required by fresh crude sewage. The time during which the sewage remained in the septic tank was at first nine hours, but this was reduced first to four and then to two hours without interfering with the result of the disinfection.

This experiment differs from the one described above in which a settling tank was used, in so far as in the latter the disinfectant was added to the tank which contained the sediment; the decomposition of the sediment being thereby prevented, and a portion of the disinfectant being absorbed and thus rendered inactive. With the septic process the disinfectant does not come into contact with the sediment, which remains in the septic tank and is gradually decomposed. The products of decomposition exert a considerable influence on the dissolved organic matters in the sewage passing through the tank even in the short periods mentioned above, and it can be assumed that in the effluents from septic tanks the bacteria are chiefly free in the liquid and not enveloped in other matter.

By the addition of chloride of lime, 1 in 10,000, to the effluents from septic tanks, we were not only able to destroy coli and similar bacteria, but often the effluent from the disinfecting tank was sterile. *Bacillus coli* was, however, found in the small quantities of sludge which collected in the disinfecting tank every few weeks; but two hours' action of chloride of lime, 1 in 5000, on this sludge was sufficient to kill all bacteria.

After disinfection the septic tank effluent was conducted on to a percolating filter of sixty-five square yards' surface area, at a rate corresponding to about a million and a quarter gallons per acre daily, this quantity being discharged within twelve hours. The action of the filter was in no way injured during the several months it was in operation.

I believe that the above investigations represent a decided progress in the technical details of sewage disinfection. After the experiments had been concluded, the third edition of Rideal's book on Sewage Purification appeared, in which it is stated that the Indian Government has carried out experiments on the river Hooghly. Chloride of lime was added to septic tank effluents, and complete sterilisation was obtained.

Works have been constructed on the above principle in connection with the disposal of sewage at the Hamburg Emigration Halls, and they are giving every satisfaction as regards the disinfection of the sewage.

Deodorisation.—The above experiments were also undertaken with the object of seeing whether it was possible to dispose of the odorous substances which give rise to nuisances when septic tank effluents are distributed over filters. This deodorising process was easily accomplished by the use of iron salts, *e.g.* ferrous sulphate, but the effluents became black, and treatment in biological filters did not remove the black coloration. The particles of sulphide of iron, which were the cause of the coloration, were so fine as to pass through the filters. Better results were obtained by introducing a layer of iron shavings, arranged in the form of a mattress, into the septic tank. In this manner the sulphuretted hydrogen was fixed and remained largely in the septic tank. Chloride of lime is also able to destroy sulphuretted hydrogen, but for some persons the odour of chlorine is scarcely less objectionable than that of sulphuretted hydrogen. The amounts of chloride of lime necessary for deodorising purposes in the septic tank are, however, so small that an odour would only be perceptible in the immediate vicinity of the tanks. The use of chloride of lime would thus combine the prevention of nuisance from sulphuretted hydrogen with disinfection.

What has been said above will have made it clear that the disinfection of sewage is not as simple and inexpensive as it was formerly thought to be. If all the sewage of our towns were to be continuously disinfected, the cost of the chloride of lime alone would amount daily to several hundred pounds sterling for some of our larger towns. As mentioned at the beginning of this chapter, the results obtained would not be in proportion with the expenditure incurred, nor would more be achieved than by the adoption of measures which aim at the disinfection of the sewage at the bed-side of the patient. Since 1899 the mode of procedure at Hamburg in such cases has been that, as soon as typhoid or some similar disease is notified, the medical officer decides whether the patient is to be taken to the hospital. The sewage from the infectious diseases portions of all our hospitals is disinfected before being discharged to the sewers. If it is possible to carry out the disinfection satisfactorily in the home of the patient, the disinfectants are provided by the State, and delivered by an official, who gives definite instruction to the attendants as to what must be disinfected and how the process is to be carried out.

The propriety of such regulations is now generally recognised, but the question is often discussed as to whether it would not be better in cases of serious epidemics to disinfect the whole sewage of the area in question.

In Germany the decision of such matters remains in the hands of the Central Authorities. This is as it should be, for it does not leave us dependent upon the whims and ignorance of small authorities. It can be assumed that the experts of the Central Authority will keep in touch with the technical developments of disinfection, and will not require the adoption of measures which necessitate large expenditure without ensuring reliable results.

CHAPTER X.

SUPERVISION AND INSPECTION OF SEWAGE DISPOSAL WORKS.

Self-Purification of Streams.—The objects of sewage purification may be shortly described as an attempt to preserve our rivers in their natural condition, to guard them against visible pollution, and to prevent danger to the health of those living near them. Whenever sewage can be discharged into a large swift-flowing river, visible alterations in the condition of the river can be easily prevented.

The self-purifying power of water is usually underestimated. So long as water contains the usual amount of oxygen necessary for saturation, it is able to mineralise and gasify considerable quantities of putrescible substances by means of the biological processes which rapidly develop when such substances are present. This touches on the interesting subject of the self-purification of rivers, a subject about which much has been written in recent years, without, however, treating all the aspects of the question in a manner which may be considered thorough. It would be quite natural to deal with these questions in connection with the subject of biological sewage purification; for then much would appear clear which is at present somewhat nebulous. In this connection I have for a long time studied the question of self-purification, but must refrain from dealing with the subject here; for in the present state of the literature no purpose would be served except by a very full discussion of all the facts, and for this there is not space at my disposal.

The Rhine and the Elbe, for example, can receive and deal with the sewage of millions without showing any perceptible change in these mighty rivers, so long as the coarse suspended matters are removed from the sewage before its discharge. The supervision of works of this character is very simple. It is sufficient simply to inspect the plant and apparatus provided and to make a survey of the river bank. Chemical tests are quite unnecessary; for the changes which are caused by discharging the entire sewage of the larger towns cannot be chemically detected in such mighty rivers, so long as the sewage is discharged in a rational manner. The course which the sewage takes can only be detected in the increased number of bacteria in the river water, but even this trace disappears in a short distance.

Tests of Impurity.—Where the conditions are not quite so favourable, and the removal of the coarser suspended solids is not sufficient, but where much of the finer suspended matter must also be removed by means of sedimentation or chemical precipitation, a control of the process can be restricted to an estimation of the suspended solids in the sewage leaving the works, in order to see that the allowable limit is not exceeded. If the suspended solids are to be estimated in the usual manner, the determinations must be carried out by chemists in a laboratory. For practical purposes it will be sufficient to allow samples of the effluent to stand in cylinders and to see what amounts of suspended matter settle out in definite times, half an hour, an hour, or twenty-four hours. Besides this the course of the stream should be surveyed, in order to see whether perceptible alterations are to be observed. The vegetation on the banks of the stream should also be observed, and any injury to fish-life should be accurately studied.

If it is a case of a small stream receiving a comparatively large volume of sewage, it will be necessary to submit the sewage to a biological process of purification before discharging it, in order that the stream may appear to our senses to preserve its natural purity. If for the moment we dismiss the question of danger to health from consideration, all that remains is how to prevent the stream and its bed from becoming evil-smelling and sludged up. This will be accomplished if the sewage is purified to such an extent that it is no longer putrescible. Whether this has been done or not may be easily tested by keeping a sample of the effluent in a closed bottle at the ordinary temperature and observing whether an objectionable smell is produced. If not, the stream will suffer no injury from the discharge of the effluent. This test may not be sufficient if the sewage contains chemicals which prevent bacterial development and thus hinder putrefaction, but this is never the case with ordinary town sewage.

If the purification has not been satisfactory, the first indication of this will be found in the grey vegetable growths which will be found along the banks of the stream, especially attached to stones, bushes, weeds, etc. These become covered with a grey slimy mass, either flocculent or in tufts. Whenever such growths are to be found, the effluents from the purification works will become putrescent on keeping in a closed bottle. If the effluent from the works is always non-putrescible, such growths are not to be found, even if the stream consists almost entirely of purified sewage; and fish-life, which of course serves as a useful indicator in such supervision, will be in no way endangered.

The technical side of sewage purification has now been so far developed that it is possible to preserve the natural appearance of every stream, even the smallest. It is another question whether this is in every case desirable. *In districts* where everything depends upon industrial development, or in the case of a large town situated on a small stream which is not naturally pretty, it will not always be desirable. In all cases it will be necessary to give due consideration to the various opposing interests. Such questions should not be in the hands of the local authorities, but should be decided by the central authorities. The question becomes a difficult one when the source of pollution is not definite, as, for instance, the sewers of a single town, but is due to numerous causes along the whole course of the stream. If the natural appearance of such a stream has to be preserved, the supervising authorities must first be able to fix the blame for any pollution which occurs. Under certain circumstances this will be possible by observing the condition of the stream and its banks immediately below the point of discharge; and if the person concerned can show that all the samples which he has taken did not putrefy when kept in closed bottles, it will be necessary to find out whether the discharge of insufficiently purified or indeed totally unpurified liquid has not taken place temporarily. In the first place, it is necessary to find out how often any storm-water overflows have been in operation. Then the purification works should be thoroughly inspected to see if they are able to perform the requirements which are expected to be fulfilled; if such be the case, the management of the works should be inquired into. Even in such a thorough inspection, the above-mentioned tests will usually be sufficient; but it may occasionally be necessary to have numerical results of the operation of the purification works, and in such cases the necessary tests will have to be carried out by a hygienist or chemist. I should be exceeding the limits which I have placed on this book if I were to describe the tests which would have to be made in such cases. The methods which have been adopted in the Institute which is under my direction have been already published (Farnsteiner, Buttenberg und Korn, *Leitfaden für die chemische Untersuchung von Abwasser*. Munich, 1902). Much unnecessary and useless work has been done in the province of the chemical analysis of sewage. Each time I see the various publications on the subject I say to myself, involuntarily: What an amount of really useful data could have been obtained in the time! As matters are, it is scarcely possible to find a few figures among the many thousands of published analyses which can be used for purposes of comparison. Generally, figures are given referring to certain constituents in the effluent without any data as to the character of the unpurified sewage. Such figures are generally of little use. In cases where the effluent contains large amounts of suspended matter or organic substances, it may be concluded that the purification works have not been in satisfactory operation. In certain cases the analyses of the effluent may show large amounts of organic matter and yet the effluent be satisfactory. Up to the present we have not possessed a chemical test which directly measures the amount of putrescible matter in sewages or effluents. We have, therefore, had to satisfy ourselves with the aid of indirect methods. Although I do not intend to deal with the details of chemical examination here, it does appear desirable to point out the weaknesses; for, as matters stand at present, samples are generally forwarded to the laboratory with the request that they be examined. A table of analytical results is then furnished, the value of which is generally not understood by the person forwarding the sample. If now the analytical data furnished by different laboratories are compared, one is forced to the remarkable conclusion that one analyst carries out totally different investigations from another. It can thus happen that, in comparing analyses which have been carried out for years, one finds figures which are not comparable with those which one considers useful, and of which one can make as little use as those who had the analyses performed.

In England and America matters are somewhat different; for there it is customary for the same methods to be adopted in almost all laboratories. Some of these methods are, however, different from those which are recognised by German experts. The English estimations, even including that of the albuminoid ammonia, have some practical value, and the wish forces itself upon us that German experts may in time adopt the English methods of examination. This would, indeed, be a decided advantage over present conditions. Such procedure would also be in the general interest, for it would allow of the exceedingly numerous estimations which have been carried out in Great Britain being used for the purpose of judging the operations which are being carried on in Germany at the present day. It would be even better if the experts of these two nations, which now stand ahead of all others on this subject, could agree upon a common method of procedure. The reports of the English Royal Commission furnish a very good basis upon which to found negotiations, and it would be very salutary if the proper authorities of the German Empire could agree upon commencing such negotiations.

The following short account of the importance of the various methods of examination used in the supervision of sewage purification works may be added to what has already been said in Chapter V.

The *physical examination* includes notes as to the colour, clearness, or transparency, and the amount of sediment. It is not sufficient to note the colour of the liquid in the sewer or river; the sample must first be taken in glass vessels. In estimating the *transparency*, the water is usually poured into a tall cylinder, beneath which is placed a white printed sheet (Snellen's Reading Test), or a white porcelain plate upon which small black squares are engraved. The height of liquid through which it is just possible to read the letters is then estimated. The result is usually expressed as "inches of transparency." The transparency varies inversely as the turbidity of the liquid. Attempts have been made to obtain numerical values of turbidity by comparison with standards, *i.e.* suspensions of definite substances, such as diatomaceous earth; the suspended matters which escape in the effluents from biological filters have also been used in the preparation of such standards, so that they might possess the necessary coloured tints.

In order to estimate the amount of *sediment* or *suspended solids* the liquid is filtered clear, and the solids retained by the filter are dried and weighed; or two samples are evaporated to dryness, one before and the other after filtration. The dry residue from each of these samples is then weighed, and the difference returned as "suspended solids." Microscopical examination often affords valuable information as to the nature of the suspended solids.

The *chemical examination* of samples is generally conducted in Germany on the clear filtrate. The whole of the substances present in the clear filtered sewage are regarded as dissolved solids or dry residue, since it remains as a dry precipitate when the water is evaporated. It has already been shown (p. 35) how this factor is greatly influenced by the composition of the water supply. In a further examination of the total dissolved solids, great importance is often attached to the estimation of the *chlorine* or *sodium chloride*, because it is assumed that the chlorine is chiefly derived from human excreta. Such estimations have, however, only a local value, and serve chiefly to indicate whether samples of effluent correspond with those of crude sewage obtained at similar periods (see p. 37). It has also been mentioned that estimations of this character can only yield valuable information either when average samples are carefully obtained, having due regard to the flow at the time of sampling, or when the number of analyses carried out is very large.

In the supervision of sewage purification works, estimations of iron, sulphuric acid, lime, magnesia, hardness, phosphoric acid, etc., have, generally speaking, little value, so long as we are dealing with domestic sewage or town sewage which is chiefly of a domestic character. Such determinations are often of importance in connection with works for the purification of trade refuse, but it is not my intention to deal with these in this book. Even then, however, a single estimation as to whether the effluent is too *acid* or too *alkaline* is generally sufficient.

Besides the above tests, the only useful ones are those which give us information as to the *putrescibility* of an effluent. The want of a really satisfactory direct test on this point has led to the introduction of an almost unlimited number of indirect tests, the value of which I will shortly describe.

The oldest of these methods is the estimation of the *loss on ignition*. The sample is evaporated to dryness, and the residue thus obtained is ignited. The loss of weight is regarded as combustible organic matter. This method is unsatisfactory, because certain harmless inorganic substances are also volatilised in the process.

In 1849, Forchhammer adopted, as the starting-point of a new method of investigation, the fact that organic substances are strong reducing agents, *i.e.* they absorb oxygen. As a conveyor of oxygen, he used a solution of potassium permanganate which loses its colour when in contact with organic matter. The larger the amount of organic matter in a liquid the more permanganate solution will it be able to decolourise. This test is termed the *oxygen absorbed* test. A definite quantity of potassium permanganate decolourised in this process corresponds to a definite quantity of oxygen absorbed. The amount of potassium permanganate divided by 3·95, or multiplied by 0·253, gives the amount of oxygen absorbed. In Germany it is usual to state the results in terms of potassium permanganate, whilst in England and America the oxygen absorbed is usually given. This method of examination forms the basis of a whole series of methods, which bear quite different names, and which from their names would appear to be quite independent methods. Wood, for example, multiplied the amount of permanganate decolourised by five and returned the result as "organic matter." This method is very unsatisfactory, but is still to be found adopted in certain analytical tables.

Generally speaking, however, the above method at the present day is used to obtain an expression for the amount of permanganate decolourised, or, which is equally correct, the oxygen absorbed. Some analysts determine this figure by the method of Kubel, others employ that of Schulze. Both these methods agree in the use of oxalic acid to estimate the amount of permanganate decolourised, but Kubel allows the permanganate to act after the addition of sulphuric acid, *i.e.* in acid solution, whilst Schulze carries out the operation in alkaline solution. In both methods the oxidation proceeds at the boiling temperature. In 1879, Tidy recommended that the oxidation should be carried out at room temperature. This so-called "Tidy test," in which the permanganate was originally allowed to act for two and a half hours, is the one which has since been generally adopted in England. The action of the permanganate is, however, allowed to continue for four hours, or for three minutes if it is desired to estimate the amount of easily decomposed organic matter. The results obtained in the three minutes' test are compared with those obtained with the same sample after incubation for several days. The sample is regarded as satisfactory if the result of the second test is lower or not greater than that of the first. This is termed the "incubator test." The estimation of oxygen absorbed, as carried out in Great Britain, also differs from the method adopted in German laboratories in that the sample of sewage is generally first filtered in Germany, *i.e.* the suspended solids are removed before the test is performed. On this point I should like our English colleagues to adopt the German method, for the suspended matter in crude sewage is not directly comparable with that found in the effluent, from biological filters.

As already mentioned, considerable sources of error are attached to the estimation of the oxygen absorbed. It is quite impossible, as a result *of this determination* alone, to say whether a sample is putrescible or not.

The results are, however, valuable in the control of one and the same purification works. As soon, therefore, as it has been shown that the sewage of a certain town is not putrescible when its oxygen absorbed has been reduced below a certain limit, it will be sufficient to determine the oxygen absorbed, say daily. In this connection the four hours' test is very useful, without carrying out the other more complicated determinations.

If the oxygen absorbed of the crude sewage is known, and this is compared with that of the effluent, conclusions may be drawn as to the putrescibility of the effluent. In 1899, as a result of numerous experiments, I was able to state that domestic sewage is deprived of its putrescible character if purification is carried out to such an extent as to reduce the oxygen absorbed, estimated by Kubel's method, by 60 to 65 per cent. Experience gained since then has only served to strengthen this view.

The oxygen absorbed of the purified non-putrescible effluent from one sewage works may be higher than that of the crude sewage reaching another works. In such cases the analytical figures would furnish little information, unless it were possible to compare those of the untreated with those of the treated sewage.

If methylene blue is added to unpurified sewage its colour is discharged. In investigations upon the biological method of purification I employed this colouring matter in 1897. In 1902, Spitta recommended the addition of methylene blue to purified effluents, and noting if the colour is discharged within a certain time. This process has been further worked out by Spitta and Weldert. According to their observations, well-purified effluents do not decolourise the methylene blue within ten days. The method, like the previous one, depends upon the reducing action of unpurified sewage. With purified sewages, however, it is usually the sulphuretted hydrogen formed from the organic matter, and not the organic matter itself, which exercises the reducing action. Recently, on the recommendation of Fowler, another method has been adopted which also depends upon the reducing action of unpurified sewage. The purified sewage is mixed with tap water, and the sample kept at a definite temperature for a certain time (two to three days). The amount of dissolved oxygen remaining in the sample is then estimated.

Besides the estimations of oxygen absorbed and the reducing action of effluents, attempts have been made to utilise determinations of organic nitrogen and organic carbon in order to gain information as to the putrescibility of effluents. In 1869, Wanklyn, Chapman, and Smith recommended the estimation of the organic nitrogen in place of the oxygen absorbed, which was then regarded as rather worthless. In England the albuminoid nitrogen is usually determined; like the organic nitrogen, which is usually estimated in Germany, it is intended to yield information as to the amount of nitrogenous organic matter in the effluent. The process is based upon the assumption that the offensive character of sewage is due to the putrefaction of nitrogenous organic matter. Doubtless much importance was attached to the penetrating odour of ammonia which arises from the decomposition of fæcal matter and urine, and hence the amount of ammonia is generally estimated in investigations, special importance being attached to the necessity of as little nitrogen as possible being present in the form of ammonia, and as much as possible in the form of nitric acid. In sewage the odour of ammonia is usually absent; only at sewage works, where lime is used for chemical precipitation, can it be observed. Neither does putrefying domestic sewage smell of ammonia, but of sulphuretted hydrogen. The estimation of organic nitrogen is rather troublesome, and the amounts to be estimated are very small, so that the errors, when calculated into percentages, are very large. The separate estimation of the nitric acid, which is regarded as harmless, also presents difficulties, and hence a whole series of modifications in carrying out the estimations have been recommended. To the method of Wanklyn, Chapman and Smith, Kjeldahl's method was added in 1883, after a method had been devised by Frankland and Armstrong for the combined estimation of carbon and nitrogen. Later modifications are due to Iodlbauer, Ulsch, Proskauer, and Zuelzer, in which nitrates and nitrites are first removed and separately estimated. At the present day great importance still attaches to an estimation of organic nitrogen in sewages and effluents. I consider this determination to be quite unnecessary for technical purposes; for special scientific investigations it doubtless possesses a certain value.

In 1901, König published a new method for estimating organic carbon, which possessed certain advantages over the estimation of organic nitrogen, but its application in the practical working of sewage purification works is also unnecessary.

A chemical examination of sewage is usually undertaken in order to determine whether the sample will putrefy. The sign of putrefaction is the formation of sulphuretted hydrogen, and the sulphuretted hydrogen is formed from the sulphur present in the organic matter, the organic sulphur. For some years I have had experiments in progress to determine whether organic sulphur can be always detected in crude sewage or in samples of effluent which are putrescible, and whether it is always absent from non-putrescible samples. These studies originated from the above-mentioned fact that sewage is no longer putrescible if its oxygen absorbed is reduced by 60 to 65 per cent. by means of biological processes. Further experiments showed that this is not only true of the oxygen absorbed, but also that sewage in which the loss on ignition, the organic nitrogen, or the organic carbon has been reduced by the same amount by biological processes, is no longer putrescible. Purification then to this extent is exactly sufficient to attain the degree of absorption, decomposition, and mineralisation which is necessary for our purpose, namely, the removal of those matters from the sewage which are able to give rise to putrefaction.

Since now the putrefaction of sewage is always indicated by the formation of sulphuretted hydrogen, the above observations must be due to the fact that biological purification to the above mentioned extent is exactly sufficient to ensure removal of the organic sulphur. Our experiments in this direction have fully confirmed my deductions, and have led to the adoption of a method which we term "the Hamburg test for putrescibility," or, more shortly, "the Hamburg putrescibility test."

The method depends upon the conversion of the organic sulphur, after first removing the inorganic combined sulphur, into sulphide, which can then be detected by Caro's methylene blue reaction. The results of our experiments showed that all crude sewages and effluents in which the reduction of the oxygen absorbed was less than 60 per cent. gave the methylene blue reaction, whilst effluents with a greater reduction than 60 to 65 per cent. in the oxygen absorbed did not give the reaction.

For years my own standpoint has been that, where the conditions for discharging sewage into a stream are unfavourable, the object of purification should be to convert the sewage into a non-putrescible product and to prevent perceptible changes in the condition of the stream. This standpoint is now generally accepted. Recently, J. D. Watson has expressed similar views, which met with the approval of the experts present. He said the only feasible standard was, that all sewage effluents must be non-putrescent, and must continue to improve when they reached the stream itself.

Standards of Purity.—After having become acquainted with the ideas upon which chemical examinations are based, we have to face the question as to which of these methods shall be adopted in practice. Some of the English Rivers Boards employ definite standards. The Rivers Pollution Commission, appointed in 1868, formulated the following standards, stating that any liquid should be deemed polluting and inadmissible into any stream if it contains:—

1. In suspension, more than 3 parts of dry mineral matter, or 1 part of dry organic matter in 100,000 parts of the liquid.
2. In solution, more than 2 parts of organic carbon, or 0·3 part of organic nitrogen in 100,000 parts.
3. In solution, in 100,000 parts, more than 2 parts of any metal except calcium, magnesium, potassium, and sodium.
4. Either in suspension or solution, more than 0·05 part of arsenic.
5. After acidification with sulphuric acid, more than 1 part of free chlorine in 100,000 parts; and
6. More than 1 part of sulphuretted hydrogen or a soluble sulphide, in 100,000 parts.

Standards were also formulated for the colour and the degree of acidity or alkalinity.

The Rivers Boards of Lancashire and Yorkshire require that the oxygen absorbed by an effluent reaching a stream shall not exceed 1·43 parts per 100,000 (1 grain per gallon), and that the albuminoid ammonia shall not exceed 0·14 part per 100,000 (0·1 grain per gallon).

From what was said at the beginning of this chapter it will be seen that such requirements can only have a local significance, and that the operations at the sewage works may be controlled without the aid of complicated chemical reactions. Usually one of the forms of the oxygen absorbed test will be sufficient.

In Germany the question as to infection due to sewage has been studied for some decades, and it can truly be said that the amalgamation of this question with that of sewage purification caused temporarily an almost complete stagnation of the question of sewage purification. In England the question of infection is only commencing to be considered. Digby and Shenton recently recommended the sterilisation of sewage effluents before their admission to streams. They consider this practicable by means of chlorine generated electrolytically from common salt. They estimate the cost of the process at one-fifth of a penny per thousand gallons. These views were brought forward in an animated discussion at a meeting of the Royal Sanitary Institute held at Stafford, in which some of the most eminent English experts took part. The standpoint generally held was that river water in inhabited districts is not suitable for drinking purposes. According to modern ideas, the purpose of such rivers is to receive and conduct away the sewage after its putrescible character has been removed, and it should never be necessary to convert sewage into drinking water. Those who do drink water from rivers which have received sewage must bear the responsibility for any evil consequences. Towns which are so improvident as to draw their water supplies from such rivers must either bear the consequences or go to the requisite expense for sterilisation. It would even then be less expensive to sterilise only the water required for consumption. For the whole volume of sewage and the river water could hardly be rendered sterile or above suspicion from a sanitary point of view, on account of the storm-water overflows. In the reply it was mentioned that London and its suburbs, with a population of six millions, still draws its water supply from a river which is polluted with sewage. Even if London decided to provide pure water from Wales or elsewhere, years would elapse before arrangements could be made for such a course. It was stated to be unfair to disturb the peace of mind of the population of such a gigantic city with the information that it was drinking water polluted with sewage; or to force all those who discharged sewage into the Thames, or into a tributary from which also the London supply is drawn, to sterilise their sewage. I cannot share these views, but must side with those who declare that the town which will or must obtain its supply from such a suspicious source must be prepared to adopt the necessary precautions and not rely upon measures taken by others. A discussion of the question as to whether sand filtration is sufficient for this purpose does *not belong to* this chapter. For further information reference must be made to the subjects of infection and disinfection dealt with in Chapter IX.

From the above it will be recognised that the questions which arise in dealing with the subject of inspection and supervision of sewage purification works have so far not received a generally satisfactory solution. What has been said may serve as an outline, in order to give the reader an idea of the numerous recommendations which have been made and of the views which are held in various quarters.

CHAPTER XI.

THE UTILITY AND COST OF THE VARIOUS METHODS OF SEWAGE TREATMENT.

Conditions of Comparability.—On visiting sewage purification works one is always informed by the manager that the works fulfil their function excellently, and that the result is very satisfactory. This lies in the nature of things, and may be always expected. The deputations sent from various towns very often do not consider what is expected of the works they visit nor what they actually do perform. This is also to some extent natural, and can hardly be expected to change. If the members of such a deputation are told that the working costs of certain works only amount to about 1¼d. per head of population per annum, and when they see what beautiful automatic machines can be set in motion for this small expenditure, they are impressed, and believe that the technical details of some other works are not of the best, if they are told that the working expenses amount to sixpence or a shilling per head per annum.

It will scarcely be credited, and yet it often happens, that for the 1¼d. per head per annum only a very small proportion of the suspended matter is removed from the sewage, the remainder of the filth remaining in the sewage, and that at the apparently inexpensive works each cubic yard of solids removed from the sewage costs ten or even twenty shillings. At the other works, however, where the operations are much simpler and not nearly so impressive, perhaps a large proportion of the total filth in the sewage is removed at a cost of one or two shillings per cubic yard, although the cost per head may be five or ten times as great as at the first works.

It is a peculiar fact that experts are often seriously requested by municipal authorities, when passing opinions upon biological purification works, to include certain apparatus in their report, of which it is well known that these are only capable of removing part of the suspended matter and perhaps also a little grease. The hopes which are raised as to the sale of this grease by means of prospectuses suffice in certain cases to awaken a certain amount of preference for the apparatus, and the printed testimonials are believed, however improbable they may appear.

Comparative Cost.—Such experience leads me to say a few words about the possibilities and costs of the various methods of sewage purification. The easiest way of doing this would be to collect the experience of various towns, give the degree of purification there obtained, and the cost in each case. Such comparisons would, however, only be of value for those thoroughly acquainted with the local conditions of each of the works. It has already been mentioned that the system of sewerage, the methods of living, the water consumption of the various towns, the influence of trade refuse, the possibility of purifying the sewage near the town without pumping, local influences on the cost of materials from which the works can be constructed—a point which is specially important in the case of biological purification—and many other points, must be considered, any one of which is sufficient to show the futility of making general comparisons. Hence, at this point I wish to lay stress upon the facts, and partly repeat the conclusions at which we have arrived in considering the various methods of sewage purification, in order that they may be before the reader in a general and collected form.

Cost of Sludge Removal.—We will first consider those methods by which nothing more can be obtained than the removal of suspended matter from the sewage. The amount of suspended matter in town sewage varies, as we have seen, generally from about 30 to 60 parts per 100,000. In this estimate the coarser solids which are generally removed before filtration through filter paper are not included. Their quantity is, however, so small as not to appreciably alter the average figures. The reasons for such a considerable variation have already been given. Each 1000 gallons, then, of town sewage contains from 3 to 6 lbs. of suspended matter. In England it is generally considered that if these matters are almost completely removed, by some such method as chemical precipitation, the sewage has been deprived of half of the solids which are of hygienic importance.

Investigations carried out with detritus tanks have shown that it is possible to retain about one-twelfth of the total amount of suspended solids by their use. The solids retained in detritus tanks are usually easy to handle. As a rule, they are composed mainly of mineral detritus or similar heavy matter, which contains only little moisture, at most about 35 per cent., and which can therefore be shovelled into carts and carted away. The total volume of such material is generally not more than 1·3 cubic yards daily from a population of 100,000.

The amount of the solids removable from sewage by means of gratings, screens, etc., varies very considerably, as is only to be expected from the variations in the forms of apparatus described in Chapter VII. If we leave out of consideration screens which are intended primarily to protect the sewage pumps, and which have therefore very wide openings, and if we only consider those forms of construction which are intended to reduce the amount of the suspended solids, it may be stated that a pound of material is removed for every 22 to 45 persons, according to the size of the apertures of the screens, *i.e.* 1·3 to 2·6 cubic yards per day from the sewage of a town having a population of 100,000. At a certain large town, however, where the screening arrangements and detritus tanks are technically as near perfection as possible, I am informed that the screens and detritus tanks remove about 7·8 cubic yards of solids per day per 100,000 population, *i.e.* over twice as much as is usually removed by means of apparatus which is generally regarded as satisfactory.

The cartage and disposal of the solids retained by screens does not cause any difficulty. The mass is usually fairly solid, containing about 70 per cent. of moisture; and although it only possesses a distant resemblance to stable manure, this resemblance is sufficient to awaken the interest of farmers. They are almost always willing to pay something for the solids removed from sewage by means of screens. The income from this source cannot, however, be considerable, since the amount of solids thus removed is only small. In London the amount of screenings removed from the sewage amounts to about 18 cubic yards daily, and these are burnt in a furnace.

The work performed by detritus tanks, screens, etc., has chiefly an æsthetic object. From a hygienic standpoint it can be of little importance to remove such a very small proportion of the total filth from sewage before discharging it into a river. There is, however, the possibility that pathogenic germs might be contained within the coarser suspended solids, and thus be protected until they travel down stream for some considerable distance, or become attached to the river banks in bathing establishments, or in some other manner are given an opportunity to spread infection. Even if this were not theoretically possible, it would still be reasonable to require every town sewered on the water-carriage system to adopt measures to prevent the discharge of the coarser suspended solids in the sewage into the stream. The total cost of such measures in large and medium-sized towns should not exceed about one to three pence per head of population per annum, and it is to be hoped that this cost will be still further reduced as technical progress is made. It would not be justifiable to draw a comparison between what has been said as to the achievements and cost of the above methods and what follows with regard to other methods of treatment.

When sedimentation is adopted, the sludge obtained is not solid, but is of a thick liquid nature. It may indeed be pumped, but is very difficult to deal with further. This sludge usually contains only 5 to 10 per cent. of solid matter and 90 to 95 per cent. of water. The water can be removed from such sludge only with difficulty, and all attempts to drain it dry have failed. If allowed to stand in open tanks with porous bottoms it is often months before the sludge is solid enough to be raised with a shovel, and each shower of rain restores its original liquid character. In Wimbledon, for example, after treatment in this manner for six months, the sludge was still a thick liquid mass containing 77·5 per cent. of water, and remaining very offensive in character. If these large amounts of sludge are placed in sludge lagoons, as is usually the case in England, they form an unbearable nuisance to the whole neighbourhood. In smaller towns it is sometimes possible to give the liquid sludge a more solid character by mixing it with house refuse and utilising it for compost, the heaps of which are not quite so bad, yet smell very strongly. There used to exist sewage purification works in which every available inch of ground not occupied with settling tanks had been gradually converted into sludge lagoons, so that the fresh sludge produced daily could not be disposed of. It was therefore regarded as a veritable salvation when it was discovered, about thirty years ago, that the sludge could be converted into a solid mass in a few hours by means of filter p 225 145 presses (fig. ~~144~~). There are chamber presses and frame presses, the latter being generally preferred. The principle upon which they are worked has been already described. The thick liquid sludge, containing 90 to 95 per cent. of water, obtained by the use of chemical precipitants, can be reduced to about a fifth of its volume in about three-quarters of an hour. The sludge cake thus obtained usually contains about 50 per cent. of water. The sludge from sedimentation tanks cannot generally be pressed without the addition of 3 to 5 per cent. of lime. The cost of this added lime, together with the operation of the machinery, works out at about two shillings per cubic yard of sludge cake obtained, or for the pressing of five cubic yards of wet sludge.

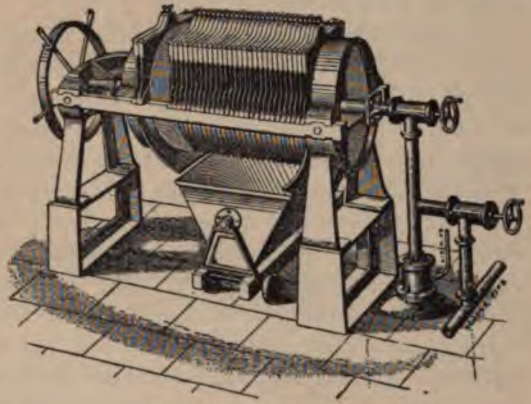


FIG. 145.—Sludge Press.

The recognition of the fact that the sludge can only be pressed with the aid of chemicals has largely contributed to the extended application of chemical precipitation methods in England. According to calculations of Santo Crimp, the total cost of sewage treatment, including sludge pressing, is largely influenced by the amount and nature of the precipitants employed. An example of this is furnished by Wimbledon, where precipitation with lime and an iron salt yielded eight tons of sludge cake per million gallons of sewage, at a cost of 2s. 6d. per ton for pressing, or £1 per million gallons. By increasing the amount of lime used for precipitation, the cost of pressing was reduced to 1s. 8½d. per ton of sludge cake obtained, but the amount obtained was twelve tons instead of eight per million gallons. The cost of pressing therefore remained the same as before, more had been expended on chemicals, and besides this, three tons of unsaleable sludge were produced instead of two. By careful consideration of all such factors where the sludge had to be pressed, the practice has been adopted in England of adding the chemicals to the sewage before settlement, and the amount of precipitant is so chosen as to yield a minimum amount of sludge cake.

It was believed that chemical precipitation effected the removal, on the average, of about 50 per cent. of all the decomposable matters present in sewage It was soon seen, however, that this was not sufficient to preserve the condition of small water-courses which received large volumes of treated sewage, and hence chemical precipitation came to be regarded merely as a palliative.

In London the sewage of a population of about four and a half millions amounts to 200,000,000 gallons daily, yielding 5500 tons of sludge per day, or yearly about 2,000,000 tons, containing on the average 91 per cent. of water. The chemicals used are 6 or 7 parts of lime and 1·4 parts of ferrous sulphate per 100,000 parts of sewage. The volume of sludge produced amounts to 0·66 per cent. of the volume of sewage; it is pumped into tank steamers and carried out to sea. At Manchester 2·5 parts of lime and about 2·0 parts of ferrous sulphate were used per 100,000 parts of sewage, the sludge produced being 0·35 per cent. of the volume of sewage. At Manchester, also, the sludge produced by chemical precipitation was carried out to sea, 188,000 tons per annum, at a cost of £5500, but the use of chemicals has now been abandoned. At Glasgow, where precipitation with lime and an aluminium salt has been adopted, the sludge produced amounts to approximately 0·9 per cent. of the volume of the sewage.

At Leipsic, clarification by means of iron salts produces 0·4 per cent.; at Pankow, lime and an aluminium salt yield 0·8 to 0·9 per cent.; and by the lignite method of treatment the sludge produced is over 2·5 per cent. of the volume of sewage treated.

The amount of sludge produced by chemical precipitation is considerably greater than by settlement alone. A comparison of the published figures would lead to the conclusion that chemical precipitation produces about three times as much sludge as sedimentation, but the figures as they stand are not strictly comparable. For example, the very thorough precipitation process which is practised at Leipsic yields comparatively little sludge, but all fæcal matter is not discharged into the sewers. The Leipsic figures for precipitation are therefore not comparable as they stand with those obtained for sedimentation at Cologne, Cassel, and Hanover. Theoretically the larger amount of sludge produced by chemical precipitation is partly explained by the fact that chemical precipitation effects a more thorough removal of the suspended matters. From the published results of towns where analyses have been regularly performed, this removal amounts to 75 to 85 per cent. of the suspended matters, as against 60 to 70 per cent. effected by sedimentation. This difference is not sufficient to explain the differences which are observed. The chemicals themselves increase the amount of sludge; a pound of lime, for instance, yielding not a pound but ten pounds of sludge, since the lime as sludge contains 90 per cent. of water. The sludge obtained from sedimentation contains, as a rule, the same amount of moisture as that produced by precipitation. Only when the velocity of flow through the tanks is increased, as at Cologne, for experimental purposes, does the sludge contain less water, for then the finer suspended solids, which attract more moisture, are washed forward into the stream. The finer the particles of sludge the more water does the sludge hold. The 5 to 10 per cent. extra solids which are separated by chemical precipitation may therefore cause a very considerable increase in the amount of sludge. In all these calculations it must always be remembered that sludge with 90 per cent. of water occupies twice the volume of sludge with 80 per cent. of water; and that a ton of sludge with 80 per cent. of water, two tons with 90 per cent., and four tons with 95 per cent., all contain the same amount, about forty pounds, of solid matter. These figures serve to show how important it is to obtain a sludge containing as little water as possible, by suitable selection of chemicals and the observation of various precautions in the operations of the works. The obtaining of a sludge containing only a few per cent. less water may mean a very considerable reduction in working expenses.

If the cost of a method of purification were to be calculated on the cost necessary to remove a ton of sludge from the sewage, chemical precipitation would appear as the cheapest; for by this process the removal of a ton of sludge costs from a shilling to eighteenpence. By means of sedimentation the cost is from four to six shillings, and, by means of screens, ten to twenty shillings. Such figures are, however, very deceptive; for chemical precipitation yields two to three times as much sludge as sedimentation, without the hygienic value of the result being two to three times as great. If the cost per million gallons of sewage treated is calculated, the results are also deceptive; for, according to the water consumption of the town, the same volume of sewage may be represented by two or three persons in one town and by ten or more in another. Birmingham, for example, with a population of 820,000, produces 25,000,000 gallons of sewage daily, *i.e.* less than that produced by Manchester, with a population of about 600,000.

If we calculate the amounts of sludge which it is possible to remove from sewage by the above methods, we find that detritus tanks yield 18 to

22 pounds per head per annum, sedimentation about 220 pounds, and chemical precipitation about 660 pounds. These figures are, of course, only rough estimates.

What has been said above regarding the various methods of removing solid matter from sewage has been said on the assumption that after such treatment the sewage was to be discharged direct to the stream. Quite as often, if not oftener, it is a question of preparing the sewage for biological treatment, *i.e.* so treating it that it will not sludge up the biological works, be they irrigation areas, intermittent land filters, or artificial biological filters. In such cases, also, it is desirable to remove as much suspended matter as possible from the sewage. But special importance attaches in such cases to the removal of the finer flocculent solids; for the fine fibrous materials which contain large amounts of water are specially liable to stop up the pores of biological filters. Besides these, grease and oil are the chief dangers to which biological works are subject.

If the biological filters are of very fine material, as in the cases of irrigation and intermittent land filtration, it can be assumed that the fine suspended matter will not penetrate very far into the filter, so that it can afterwards be removed from the surface. In small works such a procedure can be recommended almost without exception; at any rate, in preference to the use of apparatus which requires continual supervision, as is the case with screening apparatus and settling tanks from which the sludge must be removed every few days. With larger irrigation farms and land filters, which are usually situated at some distance from dwelling houses, and hence require the constant attendance of someone, the opposite course is to be recommended, *i.e.* the previous removal of the suspended matters as far as possible from the sewage. The experience gained at Birmingham strongly supports this view. At Leeds, as we have seen, the conclusion was reached that artificial biological filters should be constructed of very coarse material and receive the sewage containing all the suspended matter, with the exception of that removed by screens. The stable portion of these solids is then to be washed through the filters and removed afterwards as a non-putrescible sludge. Such measures are, of course, only possible if the apparatus for the distribution of the sewage is selected accordingly. The sewage must not be fed through fine holes, such as those in rotating sprinklers, or in some forms of fixed spray jets. Even at Leeds it was afterwards decided to remove the suspended solids by chemical precipitation before conducting the sewage on to biological filters. This is a question which can only be decided in each individual case. I have always adopted the view that, with all biological works, the suspended matter should first be removed as far as possible from the sewage, and I am of the opinion that biological filters should always be preceded by sedimentation or septic tanks. I doubt whether the present fashion of subjecting sewage to a chemical precipitation preliminary to biological treatment will last. Only in a few instances, such as at Leeds, with its peculiar trade refuse, at Salford, and at Bolton, will such a course be advisable. It can only be advisable under very exceptional circumstances for towns which are chiefly residential. In any case, the influence of the chemicals upon the processes of absorption and biological decomposition must not be lost sight of. I do not share the general idea that lime is beneficial to these processes, because it favours the formation of nitric acid; in my opinion there is always the possibility, in the absence of lime, for the nitric acid to combine with ammonia.

According to published data, the cost of sedimentation amounts to threepence, or sixpence per head per annum; at Cassel, for example, the cost is fivepence to sixpence, at Allenstein threepence, and at Frankfort-on-the-Maine fivepence, or, including interest, sevenpence. With chemical precipitation the cost is estimated at ninepence or tenpence per head per annum; at Leipsic, for example, it is ninepence halfpenny, at Frankfort tenpence (including interest and sinking fund), and at London eightpence halfpenny.

Septic treatment is cheaper than sedimentation. Moreover, as we have seen, it possesses the advantage that it produces a less volume of sludge which can be more easily drained. Such sludge has finished putrefying, and does not therefore cause a nuisance to the neighbourhood. It can also be used for filling in waste ground and for similar purposes. From sedimentation and chemical precipitation, on the other hand, the sludge obtained is watery, and its disposal is the cause of difficulty and expense, on account of its putrescible character and the large amount of water which it contains. Numerous experiments have been undertaken with the object of converting this sludge into a solid transportable mass. At Frankfort this problem has again been recently attacked in a thorough manner. By means of a centrifugal machine they have succeeded in obtaining in a few minutes a solid mass containing about 70 per cent. of moisture. Just as in pressing so in centrifuging, the addition of lime (1 per cent.) proved to be advantageous. It is intended to mould the centrifugalised sludge into briquettes by means of brick presses, to allow the briquettes to dry in the air like bricks, and then either to grind them up for manure or to burn them for heating purposes and the production of gas.

The question of the treatment and disposal or utilisation of the residues at town sewage works remains still under discussion. Each of the many processes recommended raises hopes of financial gain. The Frankfort experiments have demonstrated that quick drying of the sludge and its conversion into an unobjectionable product is only possible as yet by means of a very complicated and expensive process.

Wherever it is possible to obtain a sufficient area of suitable land in the neighbourhood of the sewage works, the cheapest method of disposal will be to conduct the sludge into furrows and cover it with soil. Such a procedure was formerly in use at Birmingham (figs. 146 and 147). The land will take a fresh quantity of sludge at periods varying from one to three years.

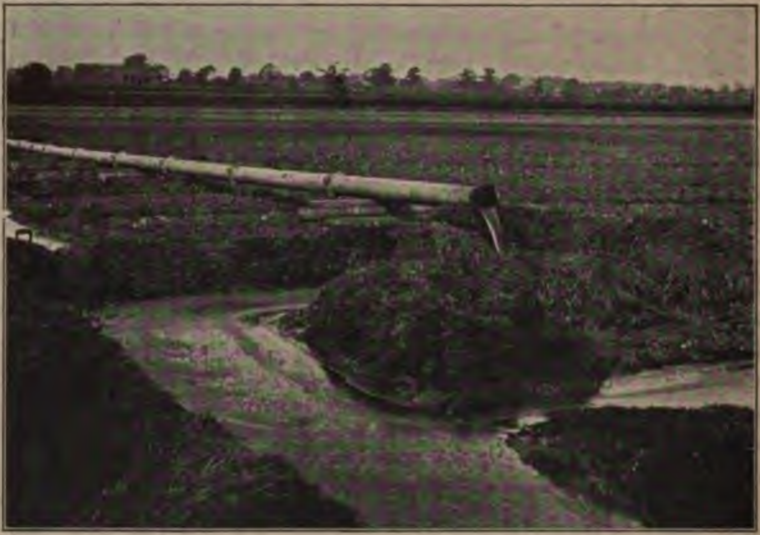


FIG. 146.—Pumping Sludge to Sludge Beds (Birmingham).

Cost of Biological Treatment.—A short time ago it was thought possible to purify sewage much more cheaply by means of artificial biological processes than by chemical precipitation. This hope has not been realised,

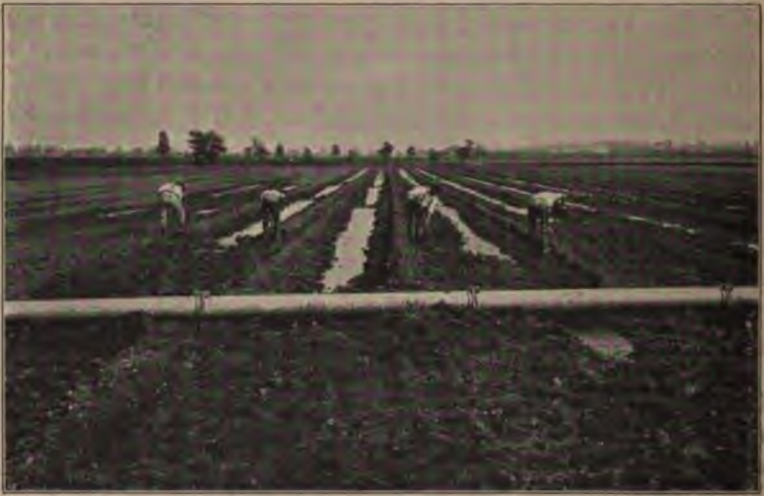


FIG. 147.—Burying Sludge (Birmingham).

and to anyone having some acquaintance with the problem of sewage treatment it must have appeared from the first unrealisable. From the experience which has been gained, however, it may be assumed that biological treatment can be carried out at a cost of ninepence to tenpence per head per annum. The following figures, taken partly from the literature on the subject and partly from municipal reports, serve as a general guide on this point: Manchester, 8·0 pence; Hendon, 4·4 pence; Swinton, 15·5 pence; Accrington, 9·0 pence; Unna, 6·5 pence; Mülheim (Ruhr), 5·0 pence; Merseburg, 4·5 pence; Langensalza, 8·0 pence; Brockau, 12·5 pence, etc. Artificial biological treatment is therefore, generally speaking, not more expensive than chemical precipitation; neither is it much cheaper.

In view of the fact that in the case of artificial biological treatment an actual purification of the sewage is achieved, whereas under the most favourable circumstances chemical precipitation only produces clarification, the biological method must be considered as by far the superior of the two. It may now be regarded as a definite fact, that this process has put us in possession of a method which is universally applicable, and which yields a product satisfying all sanitary requirements, except those relating to disinfection, even under the most unfavourable conditions of the stream into which the effluent is discharged. The results of the artificial biological method are not only satisfactory with regard to the protection of our rivers, but also with regard to the sludge disposal problem, which receives a much more favourable solution than with either chemical precipitation or sedimentation. This has been shown sufficiently in the preceding chapters.

The qualitative results of artificial biological treatment may be classed along with those of land filtration and irrigation; in this connection, however, one scheme is not applicable to all cases, and the results can be varied within wide limits. By proper attention to the processes involved in this method of treatment, results can be obtained which are quite equal to those of good irrigation farms. Irrigation is still regarded as superior with regard to the removal of infectious germs, but this view must be accepted *cum grano salis*. The best irrigation farms do not afford a guarantee in this direction; and by the adoption of certain measures for disinfection in connection with the biological method, any deficiency in this direction can be done away with, and the process thus rendered equal to irrigation, indeed better, quite apart from the fact of its universal applicability, a point which cannot be made in favour of irrigation. What has been said of irrigation also applies to land filtration.

Attempts to utilise the matters contained in sewage, experience has taught are generally expensive, and do not yield financial gain. This applies equally to irrigation farms and to grease recovery plants, etc.

I am convinced that it would be cheaper for many towns to abandon irrigation and replace it by artificial biological processes. It appears fairly certain that this will be the course of affairs as soon as the growth of the towns exceeds a certain limit. I do not doubt, for example, that many of us will live to see the day when Berlin will sell its irrigation farms for building purposes and construct artificial biological works in their place.

INDEX.

ABC process, 24.
Absorption, 142, 164.
  theory, 143.
Accrington, 89, 179, 195, 209.
Acts of Parliament, (1388) 8, (1847) 6, (1858) 7, 22, (1861) 7, (1866-7) 22, (1872) 7, (1875) 8, (1876) 8, (1892) 9, (1894) 9.
Adams' automatic feed for contact beds, 184.
Aeration, importance of, 140, 159, 164.
Air in filters, analyses of, 146.
Aird, 109.
Aire, description, 2.
Alleghany, water supply, 34.
Alster, 157.
Ammonia, albuminoid, in sewage, 39, 251.
Analyses, of air in filters, 146.
  of sewage, 36, 39, 118.
  of sewage effluents, 118.
Analysis, methods of, 248.
Armstrong, 252.
Artificial biological purification, 42, 153.
  cost of, 264.
  newspaper reports on, 158.
Ashburton, 22.
Ashtead, 96.
Austin, 23.
Automatic feed for contact beds, 184.

Bacillus coli communis in sewage, 40, 152, 231.
  enteritidis sporogenes, 228.
Bacteria, in sewage, 40, 152.
  pathogenic, in sewage, 40, 230.
  removal of, from sewage, 230.
Bacteriological character of sewage effluents, 117.
Bailey Denton, 24, 120.
Baltimore, 208.
Barking, 25, 98.
Barmen-Elberfeld, 79.
Barrhead, 90.
Baumeister, 35.
Beckurts, 116.
Berlin, 26, 36, 41, 108, 117, 266.
  sewage, grease in, 64.
  water supply of, 34.
Beverley, 102.
Binnie, 154.
Biological purification, 42, 153.
Birch, Killon & Co., 202.
Birmingham, 7, 32, 37, 41, 45, 86, 89, 95, 97.
  detritus tanks, 45.
  growth of, 111.
  separator, 76.
  septic tanks, 151.
  solids removed by septic tanks, 86.
  trade refuse at, 33.
Blasius, 116.
Bock, 68.
Boissieu, 97.
Bolton, 78, 99, 204, 263.
Bonn, 48.
Bordeaux, 83.
Boston, 123, 128.
Bradford, 9, 10.
Bremen, water supply, 34.
Breslau, 36, 108, 113.
Brockton, filters at, 123.
Bromberg, 49.
Brunswick, 113, 117.
Bryant, 195.
Buffalo, water supply, 34.
Bujard, 226.
Bunzlau, 26.
Burnley, 90.
Buttenberg, 247.

CAINK, 197.
Calder, condition of, 2, 3.
Calmette, 85, 213.
Cameron, 80, 84.
Candy, 195, 197.
  Caink sprinklers, 197.
Capacity, of filters, 176.
  air, 135.
  water-retaining, 135.
Carbon, organic, 37, 251, 252.
  dioxide produced during filtration, 146, 162, 166, 168.
Carnwath, 145.
Cassel, 45, 90, 263.
  no detritus tanks at, 45.
  grease extraction at, 61.
Cellulose, decomposition of, in septic tank, 94.
Central authority, necessity for, 8, 12.
  in Prussia, 18.
  work of, 15.
Cesspools, 1.
Chadwick, Sir E., 21.
Charpentier, 106.

Chemical precipitation, 42, 65, 97. 261
  first introduced, 23.
  at Frankfort, 26.
  at Glasgow, 99.
  at Leipsic, 99.
  at London, 98.
  at Wiesbaden, 26.
Cheshire, 9.
Chesterfield, 195.
Chlorine, in sewage, 37, 114.
  in water supplies, 38.
Chorley, 118.
Clay soil, 101.
Clichy, detritus tanks at, 46.
  filter at, 121.
  pumping station, 50.
Clogging of filters, 135.
Colloids, 91, 142.
Cologne, 37, 41, 46, 47, 68.
  water supply, 34.
  detritus tanks, 44.
Columbus sprayer, 208.
Commissions, Royal, dealing with sewage, (1857) 22, (1865) 6, 7, (1868) 7, (1869) 7, (1898) 10.
Concentration of sewage, 32.
Contact beds, 155.
  automatic feed, 184.
  Hamburg experiments with, 164.
  influence of nature of material, 169.
  influence of size of material, 171.
  rate of working, 156.
Corbett, 25, 154, 188, 191, 205.
Cost of biological filtration, 264.
  of Degener's process, 226.
  of land filtration, 128, 131.
  of screening, 258.
  of sedimentation, 263.
  of sewage treatment, 256.
Craigentinny Meadows, 21.
Crops on sewage farms, 109.
Crossness, 98.
Croydon, 57, 101, 109, 120.
Cultivation tanks, 96, 205.

Danzig, 26, 109.
Degener, 60.
  process, 26, 42, 100, 223.
    cost of, 226.
Deodorisation of sewage, 27.
Dervaux, 77.
Detritus, 46.
  tanks, 43.
    size of, 46.
Devizes, 184.
Dibdin, 25, 77, 121, 154, 156, 184.
  slate beds, 77, 184.
Digby, 254.
Disinfectants, relative value of, 236.
Disinfection of sewage, 27, 226, 228, 235.
  Hamburg experiments on, 235.
Dortmund, 114.
  tank, 73.
Dost, 226.
Drainage of irrigation areas, 107.
Draycott, 102.
Dresden, 47.
Dresden, detritus tank, 46.
  screen, 58.
  water supply, 34.
Ducat, 195, 205.
  filter, 205.
Dusseldorf, 46, 47, 52.
Dziergowsky, 86, 92, 149.

Ealing, 118.
Eccles, 102.
Edinburgh, 21.
Eduardsfelde, 105.
Elbe, 245.
Emigration Halls, Hamburg, 243.
Emscher, condition of, 4.
  Board, 4, 19.
Enfield, 201, 209.
Enzymes, 93.
Essen, 36.
Exeter, 80, 86, 87.

Fæcal matter in sewage, 35.
Farnsteiner, 247.
Favre, 93.
Fiddian distributor, 201.
Fidler, 78.
Filtration, biological, 42, 153.
  intermittent, 24.
  land, 24.
Forchhammer, 249.
Fosses Mouras, 82.
Fowler, 251.
Framingham, 128.
Frankfort, 26, 36, 46, 263.
  water supply, 34.
Frankland, Sir E., 132, 138, 188, 252.
  experiments of, 23, 119.
  member of Royal Commission, 7.
  method of filtration, 42, 118.
  on standards, 28, 253.
  value of sewage-disposal methods, 23.
Freiburg, 36, 108, 117, 152.
  water supply, 34.
Friedrich, 58.
Fuller, 207.

Garfield filter, 194.
Gases, in filters, analyses of, 146.
  from rivers ignited, 3.
Gaskell on work of West Riding Rivers Board, 9.
Gebhard, 216.
General Board of Health, 27.
Germany, laws relating to river pollution in, 15, 16.
Gerson, 104.
Glasgow, 56, 89, 99, 260.
Göttingen, 47, 55.
  water supply, 34.
Grease, extraction of, 59.
  extraction of, at Frankfort, 63.
  in sewage, 60, 114.
  from wool-washing, 62.
Grids, 47.
Grit chambers, 43.
Guben, 75.
Gulleys, street, 32, 47.

- Halle, 36, 73.
- Ham, Baker & Co., 203.
- Hamburg, 34, 37, 41, 47, 78, 86, 240.
  - Emigration Halls, 243.
  - experiments, with septic tanks, 84, 86, 92.
    - on intermittent filters, 139.
    - with contact beds, 164.
    - on disinfection, 235.
  - filters, 211.
  - putrescibility test, 37, 253.
- Hampton, 89.
- Hanley, 210.
- Hanover, 34, 68.
- Harrow, 22.
- Harzburg, 220.
- Hering, 207.
- Herzberg, 55.
- Hoffmann, 101.
- Hohenschönhausen, 104.
- Hooghly, 243.
- Hope, 109.
- Horfield, 193.
- Houston, 117, 228.
- Huddersfield, 7, 89.
- Humber, 2.
- Hydrolytic tank, 90.

- Infection of sewage, 41, 228.
- Insterburg, 49.
- Intermittent filtration, 24, 118.
  - Hamburg experiments on, 139.
  - importance of aeration for, 140.
- Iodlbauer, 252.
- Iron, influence of, in filters, 173, 174.
  - sulphide, 89, 142, 243.
- Irrigation, 42, 101.
  - at Ashburton, 21.
  - at Berlin, 26.
  - at Bunzlau, 26.
  - at Craigentinny Meadows, 21.
  - at Danzig, 26.
  - at Harrow, 22.
  - at Leicester, 103.
  - at Rugby, 22.
  - at Tavistock, 22.
  - cost of, 108.

- Jennings, George, Ltd., sprinklers, 201, 204.
- Joerning, 59.
- Joint Committees, 7, 9.

- Kammann, 149.
- Kimberley, 195.
- Kjeldahl, 252.
- Kniebühler's tank at Dortmund, 73.
- Knowle, 193.
- König, 16, 97, 252.
- Korn, 241, 247.
- Kremer, grease extraction, 63.
- Kubel, 250.

- Lake Forest, 151.
- Lancashire, 9.
- Land filtration, 24, 42, 118.
  - cost of, 128, 131.
- Langensalza, 75.
- Latham, 57, 120.
- Lawrence Experiment Station, 25, 121.
- Leeds, 3, 9, 10, 33, 37, 41, 86, 88, 89, 156, 189, 193, 195, 263.
  - solids removed by septic tanks at, 86.
- Leicester, 86, 102.
- Leipsic, 41, 99, 260, 263.
- Lichfield, 195.
- Liebig, 22, 101.
- Lille, 87.
- Linné, 82.
- Local Government Act (1888), 8.
- Local Government Board, consent necessary for loans, 8.
  - formation of, 7.
  - insisted on land treatment, 10.
  - requirements for septic tanks, 94.
  - and standards, 28.
- London, 11, 36, 90, 98, 263.
  - sewage of, early experiments, 22.
    - later experiments, 155.
  - water-closets obligatory, 1.
  - water supply of, 2, 254.
- Loss of material in washing contact beds, 183.
- Lowcock, 167, 191.
  - filter, 191.
- Lübbert, 179.

- Madeleine, 85, 213.
- Magdeburg, 105.
- Mairich, 44, 72, 75.
- Malvern, 191.
- Manchester, 37, 41, 46, 86, 89, 95, 157, 193, 210, 260.
  - condition of river, 3.
  - screens, 50.
  - solids removed by septic tanks, 86.
  - no street gulleys, 32, 47.
- Manurial value of sewage, 22, 27, 101, 109.
- Marburg, 46, 52.
- Massachusetts, land filtration in operation in, 135.
  - State Board of Health, 24, 121, 153.
    - experiments of, 86, 122.
- Material, size of, for contact beds, 169.
- Mather and Platt, sprinklers, 198.
- Maturing of filters, 138, 174.
- Mawbey, 103.
- Medfield, 25.
- Mellis, 120.
- Mersey and Irwell Joint Committee, formed, 9.
  - Act (1892), 9.
- Merthyr Tydvil, 24, 120.
- Merton, 98.
- Methods of analysis, 248.
- Metzger, 49.
- Modersohn, 219.
- Moigno, Abbé, 83.
- Monti, 36.
- Moule, 106.
- Mouras, 82.
- Müller, 73.
- Müntz, 120, 140, 145.
- Muller, Alexander, 83.

NAHNSEN, 73.
Nature assists processes of purification, 175.
Neustadt, tanks at, 74.
Nitrification, 88, 150, 187.
Nitrogen, organic, 37, 251, 252.
Norwood, 109.
Nottarp, 16.
Nottingham, 7.
Nuisance, from sewage, 2, 40.

OBERSCHÖNEWEIDE, 223, 226.
Ohrdruf, detritus tank, 44.
  sedimentation tank, 75.
Oldcott, 107.
Oldham, 90.
Oppeln, 68, 71.
Organic carbon, 37, 251, 252.
  nitrogen, 37, 251, 252.
  sulphur, 37, 88, 252.
Osdorf, 64.
Overworking of filters, 176.
Oxygen absorbed, 38, 250.
Oyster industry, 15, 40.

PARIS, Seine below, condition of, 3.
  Fosses Mouras in, 83.
Pasteur, 82.
Pathogenic bacteria in sewage, 39, 96, 116.
Peaty soil, 102, 132.
Percolating filters, 187.
Pettenkofer, von, 26, 29, 35.
Plenciz, 82.
Potsdam, 223, 226.
Presses, sludge, 259.
Proskauer, 226, 252.
Prussian central authority, 18.
Public Health Acts (1872, 1875), 7, 8.
Putrescibility test, 37, 253.

RATE of working, contact beds, 156.
  percolating filters, 189.
Reichle, 226.
Reid, 210, 222.
Reigate, 195.
Reinickendorf, 223.
Revolving screens, 54.
  sprinklers, 195.
Rhine, 245.
Rhyl, 58.
Richard, 83.
Rideal, 243.
Riensch, 46, 52, 58.
Rivers, Aire, 2.
  Calder, 2.
  Elbe, 245.
  Emscher, 6, 19.
  Hooghly, 243.
  Rhine, 245.
  Thames, 254.
  Wharfe, 2.
  self-purification of, 245.
  state of, in England, 2.
    in Germany, 4, 29.
Rivers Board, West Riding of Yorkshire, formed, 9.
Rivers Board, West Riding of Yorkshire, work of, 10.
Rivers Boards, formation of, 7, 9.
Rivers Pollution Prevention Act (1876), 8.
  Commissions, (1865) 6, 7, (1868) 7.
Robinson, 120.
Rotating screens, 54.
Rothe-Röckner, 80, 224.
Royal Commissions dealing with sewage, (1857) 22, (1865) 6, 7, (1868) 7, (1869) 7, (1898) 10.
  (1898) Reports, 11.
Rubner, 36.
Rugby, 22, 111.

SALFORD, 90, 97, 188, 263.
Salisbury, 193.
Salkowski, 116.
Santo Crimp, 25, 66, 154, 155, 259.
Saratoga, 151.
Sartory, 216.
Sauter, 59.
Schloesing, 120, 140, 145.
Schmidt, 68, 71.
Schneppendahl, 44, 53
Schottelius, 116.
Schreiber, 64, 114.
Schulz, R., 238.
Schulze, 250.
Schumacher, 237.
Schury, 226.
Schwarz, 68, 239, 241.
Scott-Moncrieff, 96, 205.
  distributor, 201.
Screening, 42.
  cost of, 258.
Screens, 47.
Scum on septic tanks, 84.
Sedgwick, 94.
Sedimentation, at Cassel, 26.
  at Cologne, 68.
  at Marburg, 26.
  cost of, 263.
  in septic tanks, 86.
  intermittent and continuous, 66.
  of fresh sewage, 42, 65, 66.
  velocity of sewage in, 69.
Seine, below Paris, condition of, 3.
Self-purification of rivers, 245.
Septic action, 65, 80.
    advantages and disadvantages of, 96
  tanks, Hamburg experiments on, 92.
    scum on, 84.
    solids removed by, 86.
Sewage, analyses of, 36, 39, 118.
  character of, 30.
  chlorine in, 37.
  concentration of, 32.
  discharged to public watercourses, 2.
  disinfection, 27, 42, 226, 228.
  early methods of disposal of, 1.
  effluents, analyses of, 118.
  fæcal matter in, 34.
  influence of water supply on, 33.
  manurial value of, 22, 27, 101, 109.
  methods of analysis, 247.
  sugar factory, 59.

Sewage, urine in, 34.
  Utilisation Acts, 22.
Sewers, combined system, 31.
  separate system, 31.
  water-carriage system, 2.
Sheffield, 7, 10, 89, 210.
Shell-fish industry, 15, 40.
Shenton, 254.
Sieves, 47.
Size of material, for contact beds, 169, 189.
  for percolating filters, 189, 209, 210.
Slate beds, 77, 184.
Sludge, destruction of, in septic tanks, 89.
  disposal at Birmingham, 264.
  presses, 259.
  removal from tanks, 77.
  treatment at Frankfort, 263.
Sludging up of filters, 135, 179.
Smith, John, & Co., 55.
Smith, Theobald, 231.
Soest, 223.
Soil, clay, 101.
  examination of, 132.
  peaty, 102, 132.
Solid matter, thrown into streams, 3.
Solids, in filter effluents, 196, 209.
  removed by septic tanks, 86.
Spandau, 223, 226.
Spitta, 251.
Spray jets, 205.
Sprinklers, 195.
Standards, 28, 253.
Stargard tanks, 74.
Steglitz, 113.
Stendal, 59.
Sterilisation, 230, 254.
Steuernagel, 45, 68.
Stoddart, 154, 192.
  distributor, 193.
Storm-water, overflows, 31.
  sewage, 32.
Street gulleys, 32, 46.
Streptococci, 228.
Subsoil irrigation, 106.
  water, 33.
Sulphide of iron, 89, 142, 243.
Sulphur, organic, 37, 88, 252.
Sulphuretted hydrogen, in septic tank effluents, 87, 89.
Sutton, 25, 88, 156.

TATTON, 114.
Taunton, 123.
Tavistock, 22.
Tegel, 223.
Thames, 254.
Tidy, 250.
Tipton, 195.
Trade refuse, discharged to streams, 3.
  in Germany, 16.
  in sewage, 32, 263.
  treatment profitable, 10.
Travis, 77, 90.
Trowbridge, 184.
Tweed, 15.

UHLFELDER, 54.
Ulsch, 252.
Unna, 36, 37, 210, 218.
Urine in sewage, 35.

VIENNA, 28, 41.

WANKLYN, 251.
Waring, 106, 167.
  filter, 190.
Warington, 140, 145.
Washing contact beds, 178.
  loss of material in, 183.
Water-closets, 1.
Water in sludge, 91.
Water supply, analyses, 38.
  influence of, on sewage, 33.
  volume of, to various towns, 34.
Watson, 46, 64, 76, 205, 253.
Wauwatosa, 151.
Weathering action, 87.
Weldert, 251.
West Riding of Yorkshire, conditions in, 2.
  Rivers Act (1894), 9.
  Rivers Board, formed, 9.
Wharfe, 2.
Whittaker, 195.
Wiesbaden, 26, 36, 46, 52, 114.
Wilson, 116.
Wimbledon, 98, 259.
Wimmer, 226.
Winogradsky, 88, 140, 145, 150.
Wollny, 164.
Wolverhampton, 191, 194.
Wool-washing, grease from, 62.
Wulsch, 105.

YORKSHIRE, West Riding of, conditions in, 2.
  Rivers Act (1894), 9.
  Rivers Board, formed, 9.

ZIRN, 235.
Zuelzer, 252.

PRINTED BY NEILL AND CO., LTD., EDINBURGH.